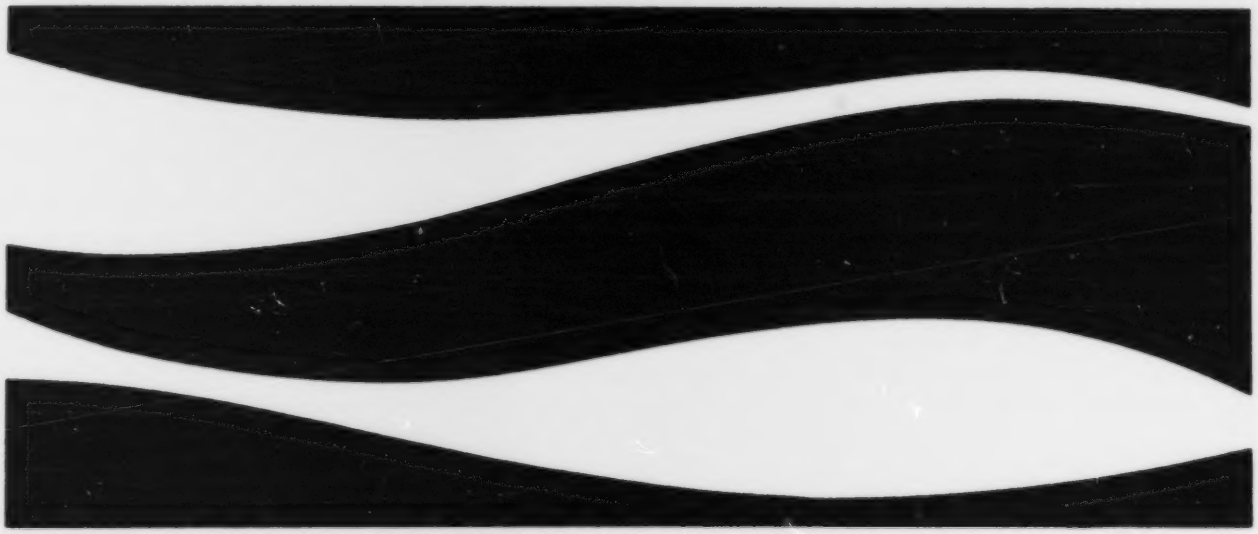
The Ecology of Fishes in British Columbia Kelp Beds

I. Barkley Sound *Nereocystis* Beds

B. M. Leaman

marine resources branch
Ministry of Environment
PROVINCE OF BRITISH COLUMBIA



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THE ECOLOGY OF FISHES IN BRITISH COLUMBIA

KELP BEDS

I. BARKLEY SOUND *NEREOCYSTIS* BEDS

by

B.M. Leaman[1]

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FOREWORD TO 1980 EDITION

This report was originally produced in 1976 as an "in house" report. The work was commissioned by the Marine Resources Branch when inquiries about kelp harvesting necessitated some knowledge of the impact such harvesting might have on commercial fish species that are found in kelp beds. Since 1976, interest in kelp and kelp products on local, national and international scales has increased significantly. In 1978, studies were initiated to expand this original work and determine how its conclusions, based on work in small bay-enclosed kelp beds, relate to the larger, open-coast kelp beds that would be targets for commercial harvesting.

Leaman's studies were among the first done on the fish communities associated with British Columbia kelp beds and constitute the only published material on fish utilization of *Nereocystis leutkeana*. As a result it was decided to publish this report for wider public distribution.

E.A. Black
February 1980

ABSTRACT

The ecology of the fish community in a Barkley Sound *Nereocystis* bed was examined and the relationships of its members to the habitat were determined. The effects of experimental canopy removal were also determined.

The plants create a habitat wherein diversity and abundance of fish species increases over non-kelp areas. The majority of resident kelp bed fish are not directly related to the plants. Indirect relationships may involve feeding, shelter or reproduction. Experimental canopy removal of the outer segments of the kelp bed decreased the abundance of neritic fish without affecting the benthic fish, whereas harvest of middle and inner segments of the kelp canopy decreased benthic fish abundance and diversity but increased these features of the neritic fish populations. Resident kelp bed fish will be affected to the least degree if kelp is harvested by patches from the middle segments of the kelp bed rather than from the more accessible seaward segments.

None of the resident kelp bed fish are of direct commercial importance, however large numbers of associated and transient fish, notably juvenile clupeoids and salmonids, are found around the periphery of the beds. The effects kelp harvesting may have on these transient commercial species should be determined in order to establish a sound kelp harvesting policy.

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Dr. Norman J. Wilimovsky and Mr. Richard Stanley provided many thoughtful comments on drafts of the Report.

INTRODUCTION

1. The Kelp Bed Resource

Beds of floating kelp plants in the coastal waters of British Columbia are generally restricted to two conspicuous algae, the giant kelp, *Macrocystis integrifolia* Bory and the bull kelp, *Nereocystis luetkeana* (Mertens) Postels and Ruprecht (hereafter referred to as *Macrocystis* and *Nereocystis*. Interest in the potential of these kelp beds to withstand continuous or seasonal exploitation for the extraction of phycocolloids and other plant products, or for the production of kelp meal as a dietary supplement for humans and livestock, has stimulated investigation of factors influencing the wise harvest of these plants. The historical utilization of kelps has not been great in B.C., although attempts have been made to utilize kelps commercially (Whyte and Engler 1974).

Beds of *Macrocystis pyrifera* C. Agardh have been exploited since the early 1900's in California, initially for potash and iodine extraction. While the plant resource in B.C. can give rise to similar finished products as are marketed in California, several factors have hampered the development of a kelp-based industry in B.C. The capital input for the establishment of the harvesting and extraction facilities is large, but, perhaps most importantly, the physical nature of kelp beds in British Columbia differs substantially from that of California beds. *Macrocystis pyrifera* is the predominant kelp of southern California where the beds have a surface area of approximately 130 - 195 km^2. *M. integrifolia* on the other hand, constitutes less than 10% of the total inventoried kelp biomass in British Columbia and covers only approximately 30 km^2 surface area. *M. pyrifera* grows in deeper water than *M. integrifolia*, thus the southern species is of larger size (20 m in length vs. 5 m in length). The kelp resource in B.C. is largely seasonal, as mediated by light conditions and damage by winter storms. The growing/harvesting season in B.C. will, therefore, be much shorter than that in California. Economically, the marginal return on proportionate capital input in B.C. is estimated to be smaller than in California.

While *M. integrifolia* is the morphological and ecological analogue of the plant upon which the California industry is based, it is not the most abundant of the commercially exploitable kelps in B.C. Beds of *Nereocystis* are both more abundant and of greater size than those of *M. integrifolia*. Beds of *Macrocystis* may ultimately prove to be the major resource in terms of product return, because of their continuous cropping potential. Nevertheless, the initial development of an industry in B.C. will most probably be based upon *Nereocystis* beds because of their greater size, density and accessibility.

Kelp beds present a unique habitat which is exploited by a variety of organisms. Knowledge of the effects of kelp harvesting on the ecology of these species is necessary to the development of a rational harvesting policy.

2. Fish in Kelp Beds

Fishes frequenting B.C. kelp beds must be examined within the framework of the seasonality of the kelp bed biotype. Fishes described as resident forms, although continually present within the kelp bed, adopt alternate habitats during periods of kelp absence. The significance of kelp beds to fish species should be considered with a knowledge of this alternation and an understanding of the role of the kelp bed in the success of survival of the species. In addition, the kelp bed may be utilized by a species in only one segment of its life cycle, i.e. spawning, juvenile rearing, adult feeding, etc.

The fish species frequenting kelp beds may be roughly divided into three categories: resident, associated and transient. Resident forms are those species which spend the majority of their time within the environs of the bed; associated species are those forms that spend the majority of their time elsewhere but are found frequently in, or near, the kelp bed and spend an appreciable amount of their time there; transient species are those species which are only

occasionally found in the environs of the bed and whose occurrences may be of a singular nature, often being found only once over long periods of time. For example, the Red Irish lord, *Hemilepidotus hemilepidotus* (Tilesius) is a resident form, often being found in the same location within a bed for several months; the Pacific herring, *Clupea harengus pallasi* Valenciennes may be described as an associated species since schools of herring are often found near the edges of kelp beds; and the Pacific hake, *Merluccinus productus* (Ayres) on infrequent occasions will make feeding forays into the kelp bed and is, thus, a transient form.

The nature of the relationships between the kelp bed and the many species found in and around its environs vary considerably in their intimacy, fidelity and duration. Additionally, species may undergo a transition in the nature of their relationship as they mature in size. The categorization of a given fish species into a certain type of relationship must be viewed with regard to its stage of life.

The literature on the biology of fishes found in kelp beds is broad and characterized by a lack of quantitative detail. The primary source of this literature has been the studies conducted on species found in California beds of *M. pyrifera*. Publications of these studies have concerned individual species families (Skogsberg, 1952; Wales, 1952; O'Connell, 1953; Roedel, 1953; Williams and Williams, 1955; Phillips, 1957; Follett *et al*, 1960; Limbaugh, 1961, 1962; Turner and Ebert, 1962; Gotshall *et al*, 1965; Bray and Ebeling, 1975; Alevizon, 1975) as well as the community of fishes in the kelp beds (Limbaugh, 1955; Davies, 1958; Quast, 1968a, b; Ebeling *et al*, 1971; Miller and Geibel, 1973; Feder *et al*, 1974). In recent years, the emphasis of research in this field has been primarily directed at individual species or 'guilds' of species which are assumed to be related to the kelp bed through food, habitat or other resource requirements. Attempts are also being made in the area of understanding the community dynamics of these fishes.

Research into the ecology of fishes frequenting B.C. kelp beds has been limited and, as yet, there are no published accounts of studies dealing specifically with the ichthyofauna of these areas. Completed, but unpublished, studies have concerned the trophic relationships of fishes in *Macrocystis* beds (Louis Druehl, S.F.U.); the distribution and abundance of near-shore fishes in the Strait of Georgia (Eftoda and LeBrasseur, F.R.B.); and, by myself, the association between the black rockfish (*Sebastes melanops* Girard) and beds of *Macrocystis* in Barkley Sound. Additionally, the Department of Fisheries and Oceans, Nanaimo (M.C. Healey) is currently investigating aspects of the utilization of the near-shore environment by juvenile salmonids.

There is a need for information on the ecology of fishes frequenting kelp beds in B.C. This need may be divided into three areas:

1) information on the ecology of resident fishes;
2) information on the associations of the kelp bed and non-resident or transient fishes; and
3) information on the effects of commercial-scale harvesting of kelp on the associated ecosystem.

The last area of information need should concern both of the categories of fish in the first two segments. The priorities for the collection of this information are, in my view, in the order I have listed them. In order to comprehend the effects of kelp harvesting, an understanding of the first two elements is mandatory and this project follows that rationale.

3. Objectives of the Project

The project was conducted to: examine the fish community of a *Nereocystis* stand in Barkley Sound; determine the relationships of the species in this community to each other and to the habitat; examine the effect of experimental canopy removal on the diversity and abundance of the species in this community; and relate these findings

to the management of the kelp resource.

The report will describe the kelp bed studied, the ecology of the fish community in it, and present the results and implications of canopy removal. Pertinent aspects of data acquisition and results are included in the body of the report; specific details may be found in the appendices.

DATA ACQUISITION

The general aspects of data acquisition are presented here. Detailed presentation of the methods and materials employed can be found in Appendix I. Field work was based, and laboratory work was conducted, at the Bamfield Marine Station of the Western Canadian Universities Marine Biological Society.

1. The Site

The study site was located on the east side of Barkley Sound in the Deer Group Islands. The largest kelp bed in these islands in 1975, which was chosen for the study, was on the north side of Diana Island at position 48^0 51.1' N, 125^0 11.4' W (Figure 1). The kelp bed was contained within a large bay having a northeast aspect. The site was initially characterized in terms of several biological and physical features: wave exposure, area, topography, general substrate nature and the distribution of phaeophyte algae.

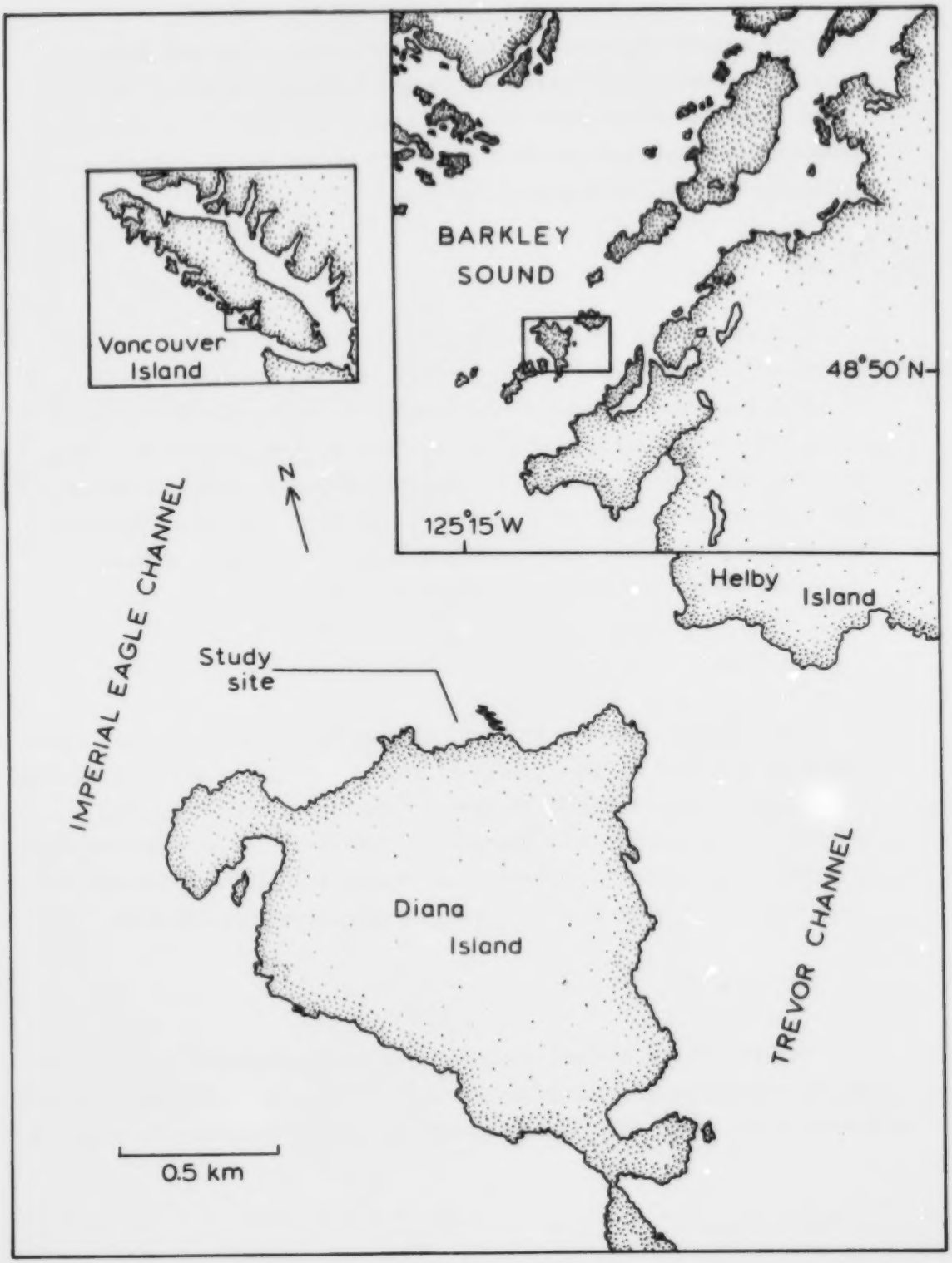
2. The Plant

The dominant floating kelp at the site was *Nereocystis luetkeana*. While the exphasis of this study was on the ecology of kelp bed fishes, efforts were made to follow changes in the plants throughout the growing season. Aspects of the plant's biology which were monitored included distribution and density, morphometrics and reproductive phenology (the timing of the release of reproductive products).

3. The Fishes

Aspects of the fishes' ecology which would yield information useful in characterizing the general nature of the kelp bed community were selected for study (e.g. species composition, distribution in relation

Figure 1. Location of the study area.



to environmental factors, use of food resources, etc.). The emphasis of the study was primarily directed at features of the fish communtiy which might be common to any kelp bed. Information on the ecology of this fish community was collected through:

1) net and chemical sampling of the distribution and abundance of fishes resident in and frequenting kelp beds, in relation to the plant distribution;
2) a tagging program which yielded data on population sizes, growth rates, residency times and movements of fishes;
3) an analysis of stomach contents which yielded data on the trophic structure of the fish community;
4) age structure, sex ratio and length frequencies of fishes in the chemical collections; and
5) field observations of fish behaviour and distribution.

4. Experimental Harvesting

In order to assess the intimacy of the relationship between the fishes and the plants, three 100 m^2 plots of plants were harvested on August 17 (Figures 2 and 3). These plots were established in the outer, middle and inner portions of the kelp bed. The plants were cut to a depth of 1.52 m (5.0 feet) below mean sea level, in accordance with a recommendation from the Branch on standardized experimental cutting operations. Pre- and post- harvesting benthic samples were taken in the plots, as well as post- harvesting samples in control areas. These cutting experiments examined the effects of canopy harvest only, not the removal of the entire plants. Nettings and observations in and around the harvested areas were made on a continuing basis as opportunities were available, e.g. net samples were only taken nocturnally.

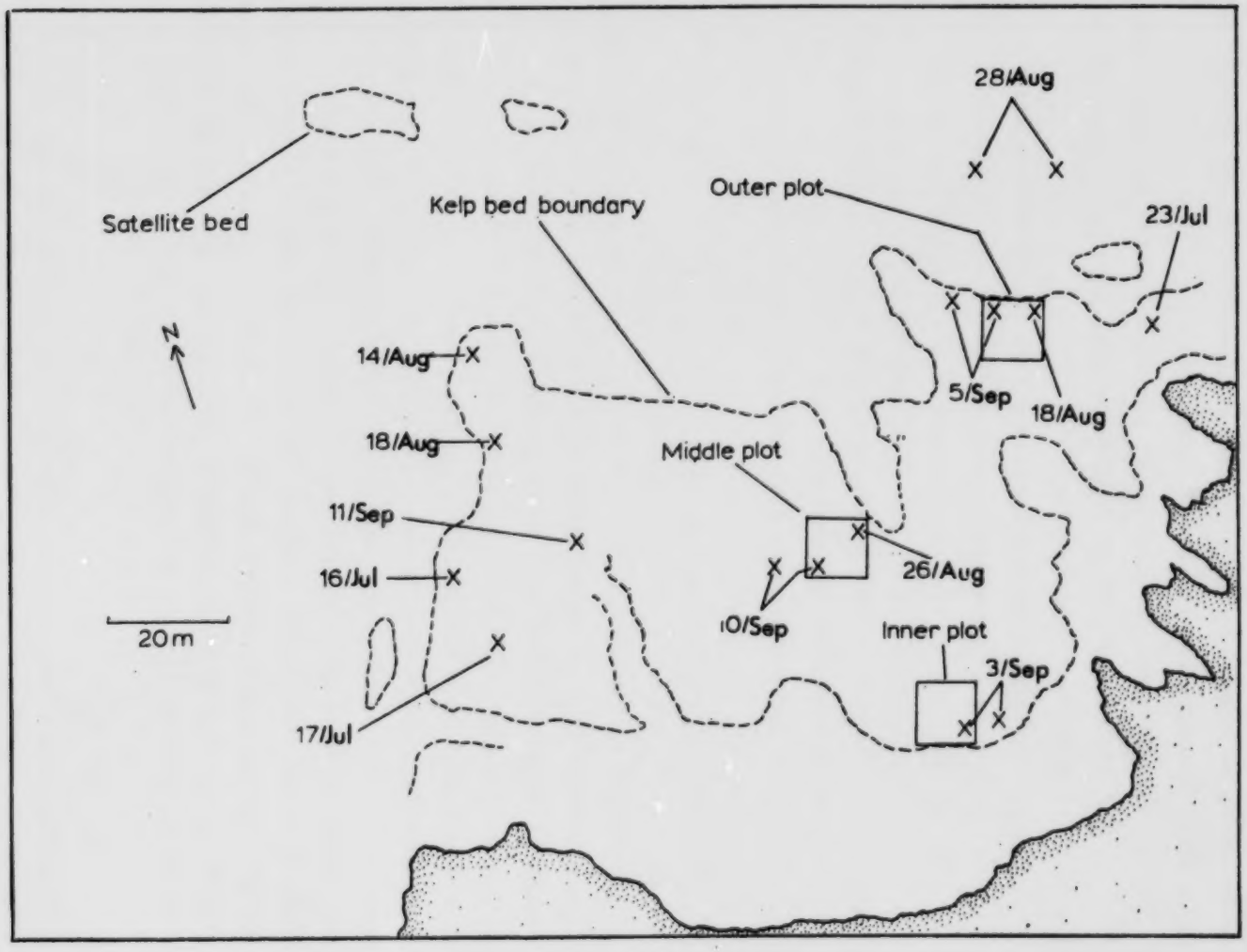


Figure 2. Large-scale map of the study site showing sampling locations and kelp bed boundaries.

Figure 3. Low-level aerial photograph of the study site, looking northwest.

RESULTS

1. The Site

The primary wave exposure at the site was from the northwest and was largely determined by the oceanographic conditions in Imperial Eagle Channel. Since the major axis of the study bed had an east-west orientation, there was a gradient of decreasing wave exposure moving from west to east. The configuration of the kelp bed was such that there were several areas subject to greater exposure than their positions along a general exposure gradient would indicate. A simplified schematic presentation of exposure gradients is contained in Figure 4.

The area of the bay which contained the kelp bed was calculated from high-level aerial photographs to be 28,000 m^2. Subsequent low-level photographs showed the kelp bed to occupy 28.9 percent of this bay, or 8,100 m^2.

Hand soundings of the kelp bed area showed the bottom to be of high relief, with a general lack of uniformity even in areas of largely uniform kelp density. Figure 5 presents a bathymetric map constructed from these sounding data. The numerous anomalies from the general substrate level were important determinants of the distribution of kelp plants and fishes. The northern face of the kelp bed was characterized by a distinct precipice, such that a transition in substrate depth from 4.6 to 7.5 m occurred in less than 1 m horizontal distance.

No attempt to classify the geological nature of the substrate was made, other than to note if it was solid or conglomerate rock. The feature of the substrate which was of primary importance in the study was whether or not it would support the growth of kelp sporophytes. All of the rock at the site was of a conglomerate type, largely irregular in formation and microtopographic relief. Large

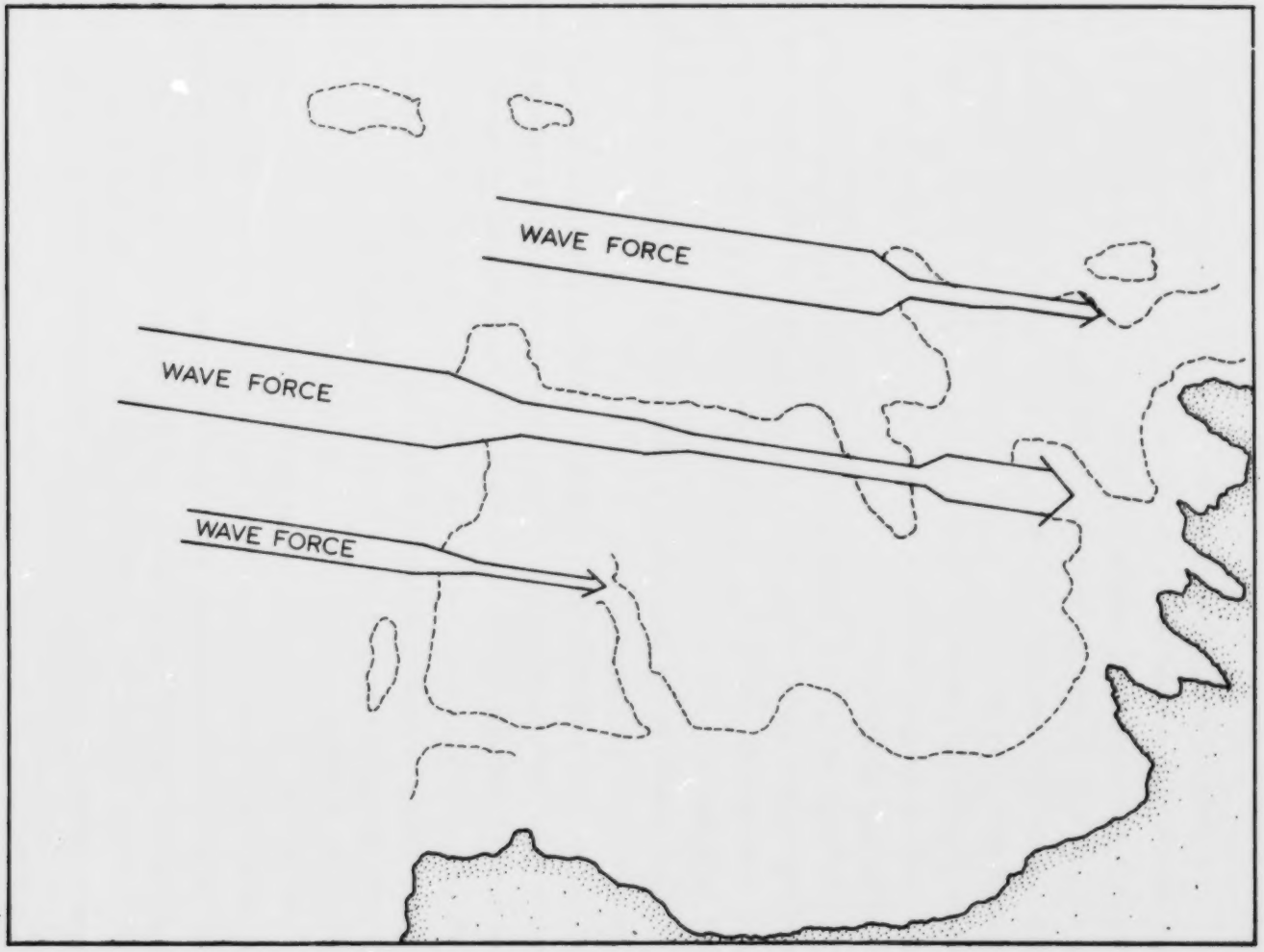


Figure 4. Generalized wave exposure gradients at the study site. Kelp bed is represented by the dashed outline. Width of arrows indicates the strength of the wave force.

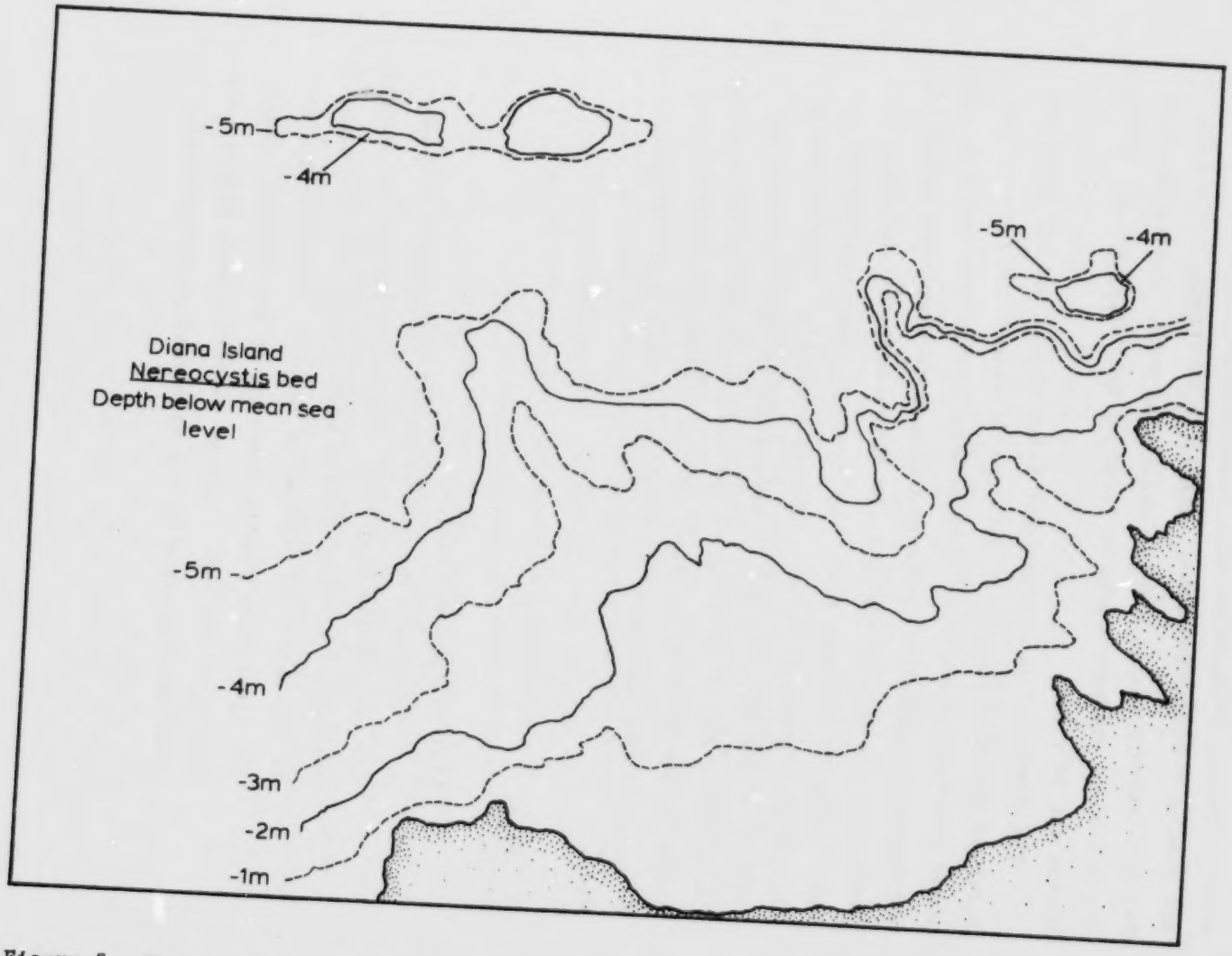


Figure 5. Bathymetric map of the study site.

numbers of crevices and depressions in the substrate were used for shelter by a variety of animals, notably the crabs, *Cancer oregoensis* (Dana), *Pachycheles* spp., *Loxorhynchus crispatus* Stimpson, and *Mimulus foliatus* Stimpson. While the substrate in the kelp bed was always rock, it was not continuous rock. Scattered rocks of 10 - 50 cm diameter could be found on the floors of the trenches within the kelp bed.

The distribution of the other kelps within the bed generally mirrored the distribution of *Nereocystis* except for the most exposed portions of the bed. *Pterygophora californica* Ruprecht and *Desmarestia ligulata* (Lightfoot) Lamaroux were the most abundant understory plants. In one portion of the bed, the shallow rock outcropping on the east side, there was an understory almost exclusively composed of *Eisenia arborea* Areschoug. The shoreward regions of the kelp bed had an understory of kelps wherein the *Pterygophora* and *Desmarestia* of the more exposed regions were replaced by *Laminaria* spp. Also, in the inside region of the bed, *Nereocystis* was supplanted by *Macrocystis* in a band averaging 5 m wide.

2. Plant

a. Distribution and density

The plant was not uniformly distributed throughout the area of the kelp bed; rather, there was an overall pattern of varying density when moving from the seaward to the shoreward regions of the bed. Table 1 presents the results of quadrat sampling at the outside, middle region of the bed, although densities were highly variable, as indicated by the wide confidence intervals.

Table 1. Density of *Nereocystis* stipes as determined by quadrat sampling at the site.

Area	Sample Size	Plant Density ($\bar{x} \pm 2$ S.E.)
Outer	6 x 1 m^2	9.3 $\pm$ 21.8/m^2
	1 x 100 m^2	6.5/m^2
Middle	6 x 1 m^2	13.0 $\pm$ 41.4/m^2
	1 x 100 m^2	8.41/m^2
Inner	6 x 1 m^2	2.3 $\pm$ 9.8/m^2
	1 x 100 m^2	1.7/m^2

Nereocystis was in extremely low abundance in the inner regions of the bed and it must be assumed that this region was a sub-optimal one for the plant. While the seaward edge of the bed was sharply delimited, this did not appear to be determined by wave stress alone. Several satellite beds (Figure 2) were located at least 25 m beyond this seaward margin of the main bed. These beds were located on rock outcroppings which were shallower than the general level of the surrounding substrate. Substrate depth was thought to be of major importance in determining the outer edge of the Diana Island Bed. In a similar fashion, the northwest edge of the bed was most probably delimited by the sand substrate in the shoreward portions.

b. Seasonal dynamics

Limited data were collected on the seasonal dynamics of the kelp plants except for changes in blade length. Figure 6 illustrates these changes over the period of the study. No relationship was found between stipe length and blade length through this period, nor was there any correlation between blade length, stipe length and holdfast area on the two occasions when these additional parameters were measured. There was a maximum in average blade length in early June which was followed by a continuous decline such that the minimum average length had a definite effect on the degree of shading provided by the surface canopy of the plants.

c. Fertility and reproductive phenology

Figures 7 and 8 illustrate the changes over time in the fertility of *Nereocystis* blades, the maturity of the sori (reproductive structures), the number of sori per blade, the average area of the sori and the total reproductive tissue per blade. The numerical data upon which these figures are based can be found in Table 2.

Blade fertility reached a maximum in early July, as did the number of sori per blade and the total area of reproductive tissue per blade. These maxima were followed be a slight decline in mid-July and a second, though lesser, peak in late July (except for reproductive tissue per blade). The percentage difference in the two maxima varied with the parameter that was measured. Fertility decreased 33% and number of sori per blade by 11%. The period following this late July peak was marked by large declines in the number of sori per blade (74%) and the total reproductive tissue per blade (88%), but these changes were not

Figure 6. Changes in the mean length of *Nereocystis* blades over the period of the study. Means are bounded by their 95% confidence limits and the range of the data.

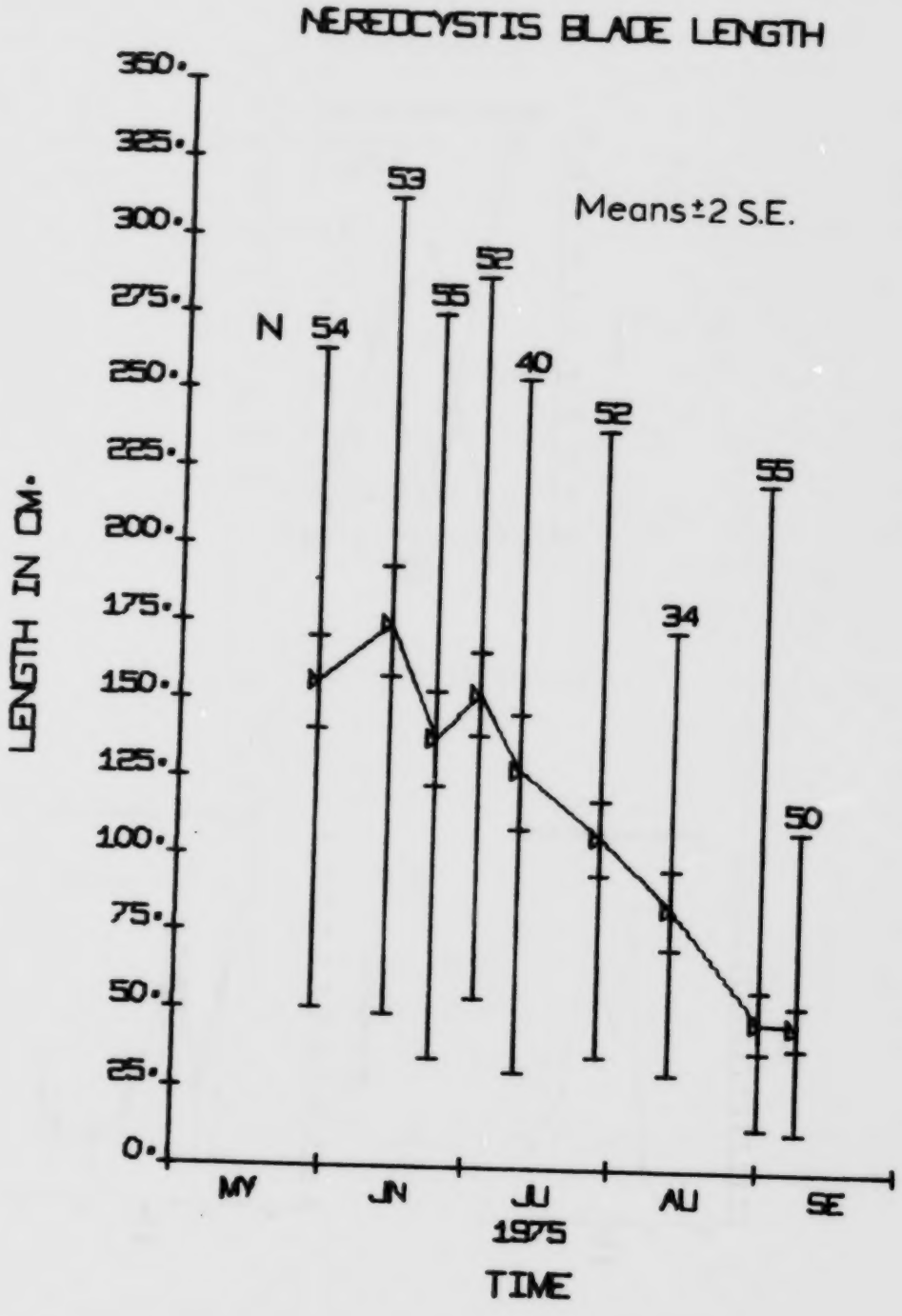
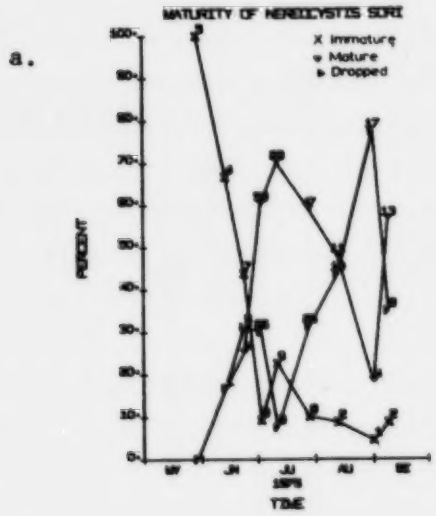
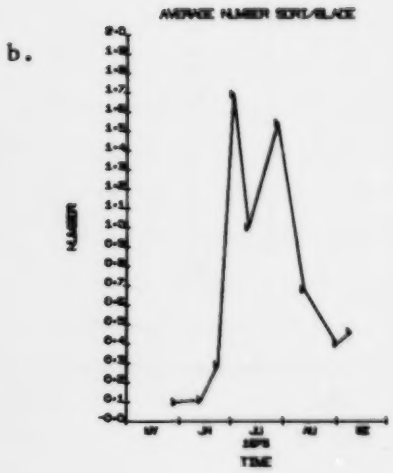


Figure 7. Maturity of *Nereocystis* sori (a), number of sori (b), and area (cm^2) of the sori (c) over the period of the study.





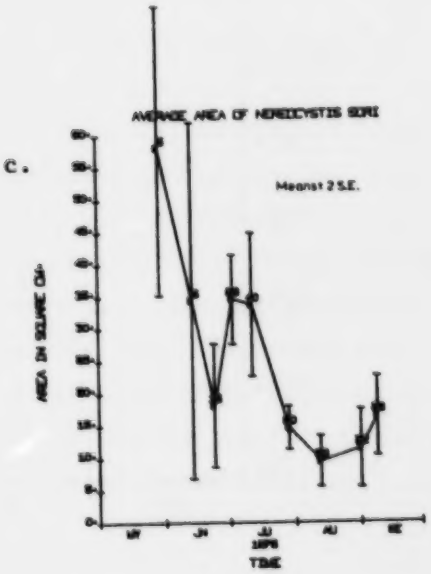
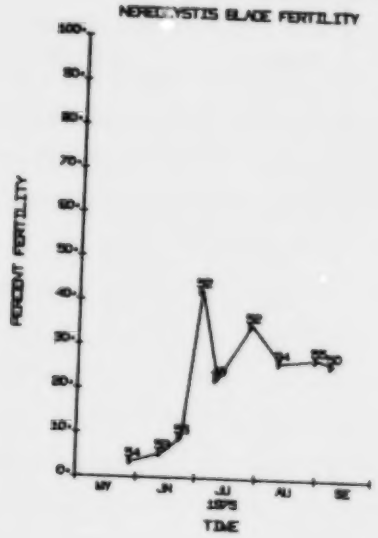


Figure 8. Fertility of *Nereocystis* blades (a) and total reproductive tissue per blade (b) over the period of the study.

a.



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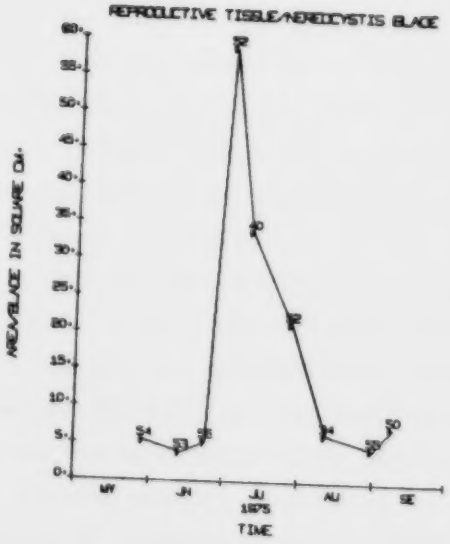


Table 2. Changes in the reproductive status of the *Nereocystis* plants over the period of the study.

Date	Number blades	Percent fertile	Number sori	Mean sori area (±2 S.E. (cm^2)	Sori area per blade
May 30	54	3.7	5	58.1±22.9	5.4
June 14	53	5.6	6	34.4±27.6	3.9
June 24	55	9.1	16	18.1±9.5	5.3
July 3	52	42.3	88	34.6±6.5	58.6
July 12	40	22.5	40	33.7±11.7	33.7
July 29	52	34.6	80	14.6±3.3	21.3
August 13	34	26.4	23	9.4 ± 3.9	6.4
September 1	55	27.2	22	11.4± 6.0	4.6
September 9	50	26.0	23	16.4± 6.1	7.5

mirrored by similar changes in the percentage of fertile blades, which decreased by only 25%. The measurement of the average area of the *Nereocystis* sori was unique in that it began at a maximum and decreased almost continuously throughout the plant's growing season.

The measurement of the total area of reproductive tissue per blade indicated that the vast majority of the output of reproductive products at this location, in 1975, centered around the month of July.

3. The Fishes

a. Species assemblage

Table 3 presents the fish assemblage of the Diana Island kelp bed as the numbers of individuals of each species captured with gillnets or collected in the chemical samples. These abundances are not absolute and they apply only to those species that were susceptible to the two sampling techniques involved. In general, the chemical was only effective in sampling benthic or epi-benthic fish and juveniles of water column fish and large individuals of benthic forms. Additionally, there were water column forms that, due to their morphology, were not susceptible to gillnet capture, e.g. Pacific hake (*Merluccius productus*).

The benthic samples were dominated by a single species, the sculpin *Artedius harringtoni* (Starks). This species was the most abundant fish in all of the samples and was the only species showing ubiquity within and around the kelp bed. Other benthic species were present in varying numbers, depending on sampling location. Appendix II provides a brief synopsis of ecological infor-

Table 3. Cumulative abundance of species in samples from the Diana Island kelp bed.

Species	Rotenone	Net
Artedius harringtoni	487	
Anoplarchus purpurescens	115	
Hexagrammos decagrammus	100	174
Chirolophis nugator	98	
Hemilepidotus hemilipidotus	96	58
Jordania zonope	80	
Phytichthys chirus	59	
Liparis florae	56	
Gobiesox maendricus	52	
Aulorhynchus flavidus	46	11
Synchirus gilli	43	
Xiphister atropurpureus	39	
Pholis schultzi	20	
Ascelichthys rhodorus	20	
Cymatogaster aggregata	17	150
Liparis mocosus	15	
Embiotoca lateralis	9	33
Bothragonus swani	8	
Oligocottus rimensis	7	
Coryphopterus nicholsi	6	
Sebastes melanops	5	543
Rhacochilus vacca	5	35
Oligocottus snyderi	3	
Hemilepidotus spinosus	3	
Nautichthys oculofasciatus	2	12
Enophrys bison	2	3
Hexagrammos lagocephalus	2	26
Apodichthys flavidus	2	
Artedius fenestralis	1	
Blepsias cirrhosus	1	5
Agonomalus mozinoi	1	
Sebastes caurinus	1	19
Engraulis mordax		310
Squalus acanthias		83
Hydrolagus colliei		72
Brachyistius frenatus		14
Merluccius productus		9
Ophiodon elongatus		6
Scorpaenichthys marmoratus		4
Pleuronichthys coenosus		2
Porichthys notatus		2
Sebastes nebulosus		2
Ammodytes hexapterus		1
Sebastes miniatus		1

mation for the major benthic species collected in the chemical samples.

Overlap in the species collected with the two methods was generally a result of juveniles of water column forms being affected by the chemical and larger individuals of benthic forms being caught in gillnets. Species represented in the net sample which were not wholly susceptible to net capture were: Northern anchovy (*Engraulis mordax* Girard), Pacific hake (*Merluccius productus*), C-O sole (*Pleuronichthys coenosus* Girard) and sandlance (*Ammodytes hexapterus* Pallas). The majority of those species collected with the chemical were considered as resident forms. The net-caught specimens, by contrast, were largely associated or transient forms, with several notable exceptions. The black rockfish, *Sebastes melanops*, and the majority of the sculpins could, through observations or tagging, be considered resident forms. Dogfish (*Squalus acanthias* Linnaeus), ratfish (*Hydrolagus colliei* Lay and Bennett), Pacific hake (*Merluccius productus*), midshipman (*Porichthys notatus* Girard), and the rockfishes *Sebastes nebulosus* Ayres and *Sebastes miniatus*, Jordan and Gilbert, could justifiably be designated as transient forms, since they were either captured in very low abundance and/or the tagging study did not indicate any localized individuals.

b. Distribution and abundance

Table 4 presents diversity indices and total information content of the rotenone samples as calculated by Brillouin's (1960) formula. The diversity indices describe how evenly the number of individuals are divided among species; the information function is sensitive both to diversity and to the total number of individuals present.

A high diversity index for a collection indicates that for each new individual encountered in the collection there is high uncertainty as to which species it will belong to. More simply, a high index means that the total number of individuals in the collection are divided more evenly among all species than for a similar collection with a low index.

Table 4. Diversity analysis of the benthic samples.

Collection Date	Species Number	Individuals (N)	Diversity (H)	Information (HN)	Evenness (J)	Habitat Type
July 16	15	94	0.81	77.1	0.008	Sheltered
July 17	15	141	0.88	124.1	0.006	Sheltered
July 23	17	122	0.77	95.2	0.006	Middle
August 14	6	13	0.52	6.8	0.069	Outer
August 18	11	50	0.61	30.5	0.014	Outer
August 26	15	124	0.66	81.8	0.005	Middle
Sept. 3	20	103	0.91	93.7	0.008	Inner
Sept. 5	10	94	0.53	49.8	0.006	Outer
Sept. 10	20	118	1.00	118.0	0.007	Middle
Sept. 11	22	162	1.04	168.5	0.005	Sheltered

The distribution and abundance of benthic species as indicated by the chemical samples was roughly the inverse to that of the *Nereocystis* plants. Samples from relatively sheltered, inner or middle kelp bed locations had both higher diversity indices and total information content than samples from outer and exposed locations. Table 5 lists the abundance of species in each of the chemical collections, as well as the type of habitat from which each col-

Table 5. Species composition of the benthic samples.

Species	Collection									
	July 16	July 17	July 23	Aug. 14	Aug. 18	Aug. 26	Sept. 3	Sept. 5	Sept. 10	Sept. 11
Hexagrammos decagrammus	16	10	2			7	1		10	15
Artedius harringtoni	34	37	63	2	27	63	35	59	31	10
Hemilepidotus hemilepidotus	9	6	7	5	7	8	6	2	9	6
Anoplarchus purpurescens	6	30	5			20	2	2	14	18
Jordania zonope	5	1	1						1	1
Phytichthys chirus	3	15	1	2	2		5	3	1	20
Hemilepidotus spinosus	1					2				
Gobiesox maendricus	1	9	8	2	3	1	11	1	3	3
Nautichthys oculofasciatus	1									1
Aulorhynchus flavidus	1	1					1		3	34
Xiphister atropurpureus	3	9	5	1	1	1	2		8	5
Synchirus gilli	7		4	1	2	2	1	9	5	5
Liparis florae	5	2	5			3	7	10	3	4
Liparis mucosus	1		2			2	1	5		1
Chirolophis nugator	1	14	6		2	6	10		11	14
Pholis schultzi		1			1	3			1	4
Apodichthys flavidus		1			1					
Artedius lateralis		2	4		3	7	7	2	6	8
Artedius fenestralis		1								
Oligocottus rimensis			3				1	1	1	
Oligocottus snyderi			3							
Bothragonus swani			2				4			
Ascelichthys rhodorus			2		1	2				2
Embiotoca lateralis						5	1			
Cymatogaster aggregata							4		5	6
Blepsias cirrhosus							1			
Enophrys bison							1		1	
Sebastes melanops							2			1
Hexagrammos lagocephalus									1	
Rhacochilus vacca									3	2
Sebastes caurinus										1

lection was taken. The diversity indices and information functions showed no consistent relationship with kelp density; however, they were positively correlated with the relative degree of wave exposure at each sampling location. While some species could be positively associated with a given habitat type, e.g. *Jordania zonope* Starks, *Ascelichthys rhodorus* Jordan and Gilbert and *Liparis* spp. in exposed locations, numerous species appeared to be unrelated to either or both of kelp density and exposure; e.g. *Artedius lateralis* (Girard) could be found in abundance in sheltered areas of both high and low kelp density, as well as in exposed areas. Conversely, *Anoplarchus purpurescens* Gill was abundant in sheltered areas of high kelp density but not in areas of low kelp density or high wave exposure.

Resident water column forms could be roughly divided into three categories with regard to their distribution and abundance:

1) species found primarily at the seaward edge of the kelp bed;
2) species found primarily at the landward edge of the kelp bed; and
3) species found more or less ubiquitously throughout the kelp bed.

The black rockfish, *Sebastes melanops*, was the most abundant species in the first category. Figure 9 illustrates the cumulative abundances of this species with the seaward edge of the kelp bed used as a point of reference to establish position. Negative and positive numerals on the abscissa indicate position in metres shoreward and seaward from the edge of the kelp bed, respectively. The figure shows the concentration of the fish around the edge of the bed, with a significantly greater number of

Figure 9. Cumulative abundance of *Sebastes melanops* inside and outside the kelp bed. Zero indicates the seaward edge of the kelp bed, negative and positive numerals on the abscissa indicate position (in metres) shoreward and seaward respectively.

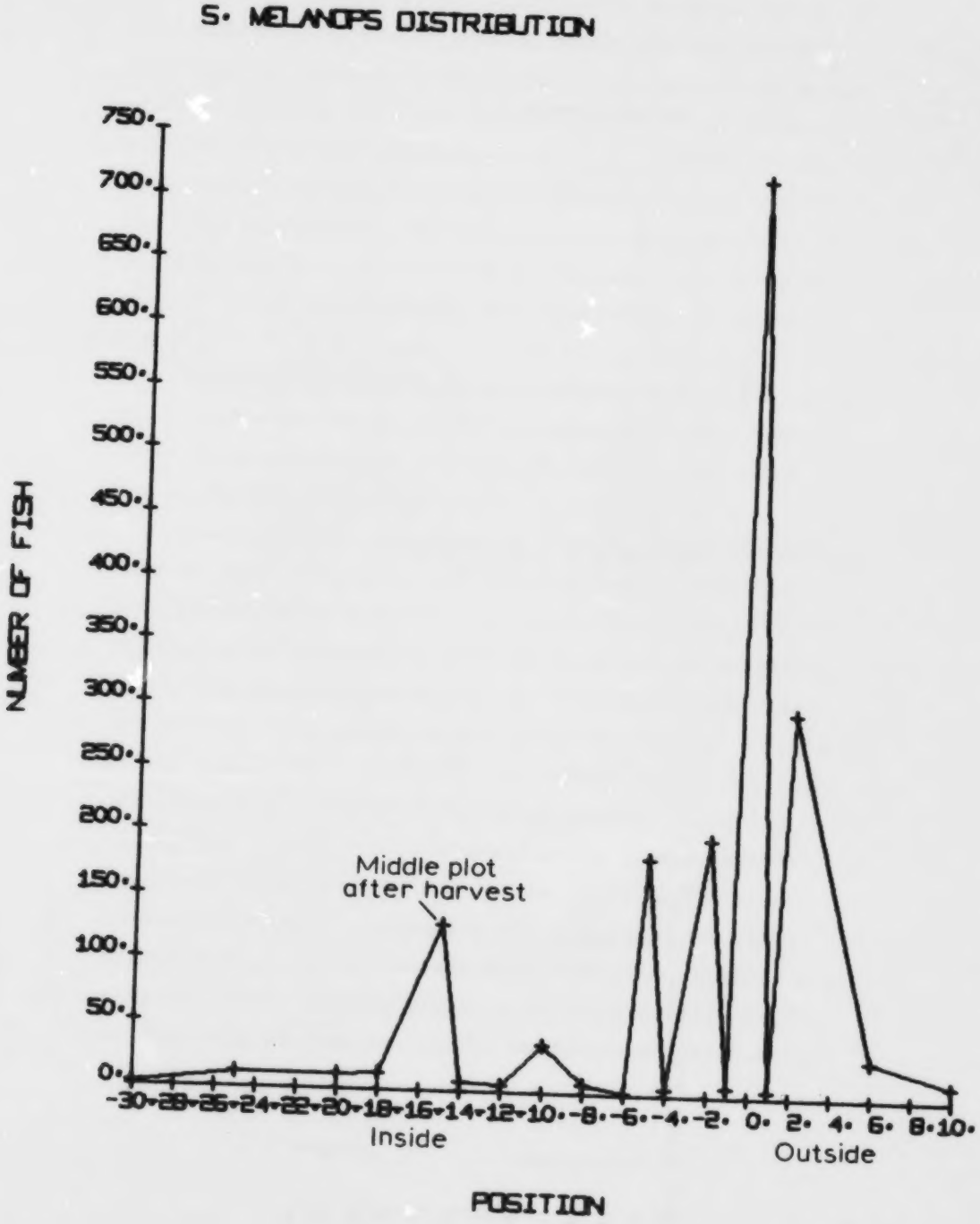
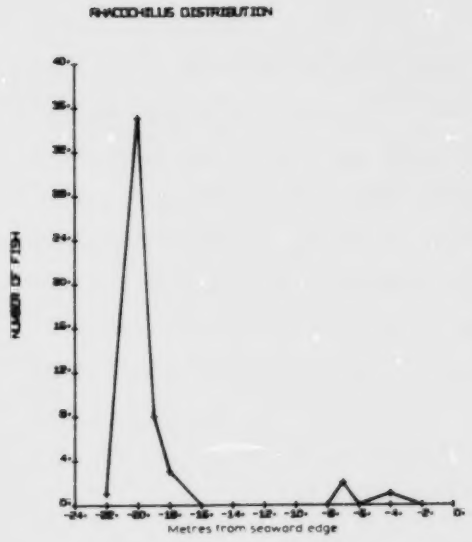
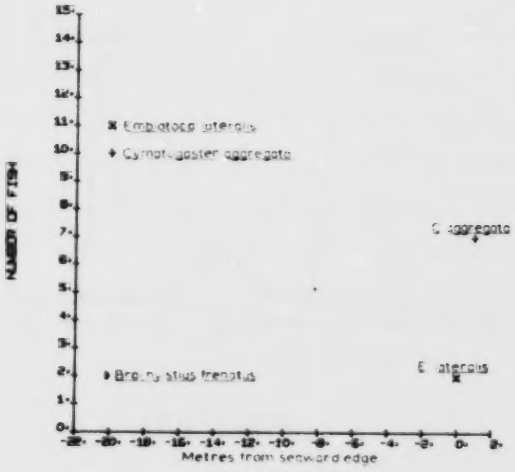


Figure 10. *Rhacochilus* distribution (a) and cumulative abundances of four embiotocid species at the landward edge of the kelp bed (b). Zero indicates the seaward edge of the kelp bed, negative and positive numerals on the abscissa indicate position in metres shoreward and seaward respectively.

a.



b.



fish being present inside the bed than outside. Although limited nocturnal observations were made, a similar pattern was indicated for these times.

Species of the family Embiotocidae (surfperches) were the most common forms consistently found at the landward edge of the bed. Figure 10 shows the cumulative abundances of members of this family, by species, at positions within the kelp bed. While the adults of these species, especially *Embiotica lateralis* Agassiz, could occasionally be found toward the seaward edge of the bed, the smaller juveniles of these species appeared to be restricted to the inner reaches of the kelp bed, often swimming in small schools among the *Nereocystis* and *Macrocystis* plants in this area.

Schools of the sandlance, *Ammodytes hexapterus*, were observed in the bed in early September and were always noted in the shoreward segments of the bed, but not as far in as the embiotocids.

The tubesnout, *Aulorhynchus flavidus* Gill, was not only the sole species of the third category, but there were reservations about the assignment of it to the category as well. While this species was found in approximately 70% of the area of the bed, its distribution was not uniform in relation to the environment or to the size of the fish. These fish were not generally present among the kelp plants, rather they formed small schools (50 - 60 individuals) in the open areas between kelp patches. These small schools were most often found in crevices, channels and other depressions below the general substrate level. There was both horizontal and vertical segregation of the fish by size. A decreasing cline in the average size of fish in schools was observed when moving

from the outside of the bed toward the shore. Fish were also segregated by size in the water column, larger fish being closer to the surface. Adult males guarding eggs presented a special case of size-associated vertical positioning. Females of this species, in this vicinity, deposit their eggs on the pneumatocysts of *Nereocystis*, around the bases of the laminae. Males guard the eggs until hatching and it was common to find adults of the species within 1 m of the surface. Since hatching in this species is protracted and there were normally several egg masses on a given plant (often at different developmental stages), adult males were common near the surface throughout the months of July-August.

The larger individuals of some benthic fishes were much more mobile than their smaller counterparts. While the smaller (<150 mm) individuals of the kelp greenling, *Hexagrammos decagrammus* Pallas, were resident forms, larger fish were associated forms. These larger fish could usually be found anywhere for at least 25 m outside the kelp bed and occasionally made forays into the bed. No significant differences were observed in the abundance of these large fish in the bed, either nocturnally or diurnally. A similar situation existed with regard to *Enophrys bison* (Girard) and, to a lesser degree, with *Hemilepidotus hemilepidotus*.

Associated fishes of the benthic variety were the lingcod (*Ophiodon elongatus* Girard), the cabezon (*Scorpaenichthys marmoratus* [Gill]) and, as mentioned above, larger *Hexagrammos decagrammus* and *Hemilepidotus hemilepidotus*. These fishes could generally be found within 100 m of the kelp bed, in deeper water. Larger *Hexagrammos decagrammus* and *Ophiodon elongatus* could be found

consistently within 25 m of the satellite beds to the north of the main kelp bed.

While schools of the Pacific herring, *Clupea harengus pallasi*, could be found consistently around the kelp bed, often within 5 m of it, it was not possible to determine whether this species could be definitely classed as an associated form. Since no herring were marked during the study, no individuals could be positively identified in the vicinity of the kelp bed and the distinction between associated and transient forms could not be made. A similar problem existed with regard to the northern anchovy, *Engraulis mordax*, which could be found around the edges and within the outer portions of the bed during the early morning hours (0400-0900). In the Strait of Georgia, juvenile salmonids are found around the periphery of the kelp beds in the late summer and possibly have the same type of relationship to the beds as these Barkley Sound forms (R.E. Foreman, personal communcation). There were, therefore, no identifiable neritic forms of the associated class.

The most abundant of the transient neritic forms were the spiny dogfish, *Squalus acanthias*, and the ratfish, *Hydrolagus colliei*. While 83 and 72 individuals of these two species were marked during the netting program, the absence of recoveries indicated that although abundant, they were probably transient forms. The Pacific hake, *Merluccius productus*, was another transient form in the area. Although only nine individuals of this species were taken during the study, its low susceptibility to net capture indicates this number was not representative of the actual numbers making forays into the bed. All of these species were nocturnally active and were never

noted in the vicinity of the bed diurnally. The remaining species included in this category were all in very low abundance and their presence in the kelp bed were thought to be random occurrences without connotations of any positive relationships (Table 6).

c. Age-group structure of selected populations

Table 7 presents age-groups present in the kelp bed for those species upon which age analysis was possible, as well as projected yearly growth rates for these species. The majority of the benthic forms, especially the cottids, were not aged. Size-class frequency plots were constructed for those benthic species for which sufficient data were available to indicate the number of age-groups present in the kelp bed. Considering only those species obtained in the chemical samples, ten of thirty-two species showed evidence of more than one year-class in their populations. A distinct bimodality of size frequency distribution indicated two age-groups in the following species: *Hemilepidotus hemilepidotus, Anoplarchus purpurescens, Phytichthys chirus* (Jordan and Gilbert), *Gobiesox maendricus* (Girard), *Xiphister atropurpureus* (Kittlitz), *Liparis florae* (Jordan and Starks), *Chirolophis nugator* (Jordan and Williams), *Artedius lateralis, Ascelichthys rhodorus, Jordania zonope* and *Artedius harringtoni*. All other species showed unimodal size frequency distributions, inferring only one age-group present in the kelp bed.

d. Growth of selected species

Growth of kelp bed forms was determined by three methods: direct measurement for recaptures of tagged fish; interpolation from age-length regressions; and

Table 6. Classification of fish species by habitat association.

Neritic - Resident	Neritic - Associated	Neritic - Transient
Sebastes melanops	Engraulis mordax ?	Squalus acanthias
Cymatogaster aggregata	Clupea harengus pallasi ?	Porichthys notatus
Rhacochilus vacca	Ammodytes hexapterus ?	Sebastes miniatus
Embiotoca lateralis		Sebastes nebulosus
Aulorhynchus flavidus		
Brachyistius frenatus		
Benthic - Resident	**Benthic - Associated**	**Benthic - Transient**
Hemilepidotus hemilepidotus	Enophrys bison	Scorpaenichthys marmoratus
Hexagrammos decagrammus	Ophiodon elongatus	Hydrolagus colliei
Hexagrammos lagocephalus	Jordania zonope	Pleuronichthys coenosus
Anoplarchus purpurescens	Coryphopterus nicholsi	
Chirolophis nugator	Hexatrammos decagrammus	
Blepsias chirrhosus		
Nautichthys oculofasciatus		
Artedius harringtoni		
Phytichthys chirus		
Liparis Florae		
Liparis mucosus		
Gobiesox maendricus		
Artedius lateralis		
Synchirus gilli		
Xiphister atropurpureus		
Pholis schultzi		
Ascelichthys rhodorus		
Bothragonus swani		
Oligocottus rimensis		
Oligocottus snyderi		
Hemilepidotus spinosus		
Artedius fenestralis		

Table 7. Projected yearly growth rates of some kelp bed species, including the method of growth determination and the number of age-groups present in the kelp bed.

D = direct measurement through tagging
R = regression of size at age
SF = size frequency analysis

Species	Size Range	No.	Growth mm/yr	Method	Age Classes
Sebastes melanops	101-150	21	163	D	4
	151-200	15	134	D	
	201-300	4	153	D	
	301-400	1	69	D	
Hexagrammos decagrammus	201-300	♀1	139	D	3
	201-300	♂8	215	D	
	301-400	♀5	285	D	
	301-400	♂5	161	D	
Hemilepidotus hemilepidotus	101-200	2	146	D	3
	201-300	8	77	D	
Hexagrammos decagrammus	201-300	4	277	D	-
Nautichthys oculofasciatus	101-200	4	142	D	2
Merluccius productus	501-600	3	85	R	2
Cymatogaster aggregata	101-200	5	126	R	2
Artedius lateralis	20-100	51	50	SF	2
Ascelichthys rhodorus	30-100	20	50	SF	2
Phytichthys chirus	30-160	59	55	SF	3
Artedius harringtoni	20-80	487	45	SF	2
Anoplarchus purpurescens	30-110	115	50	SF	2
Jordania zonope	30-90	80	40	SF	2
Chirolophis nugator	40-120	98	50	SF	2

changes in the size-classes of the modes of abundance of those benthic forms for which sufficient data were available. Table 7 presents projected yearly growth rates (assuming constant growth throughout the year) of those species for which growth determination was possible. The methods of growth determination and number of age-groups involved are also included in the table. The majority of the benthic fishes exhibited roughly similar growth rates. The exception to this pattern was the growth rate of the kelp greenling, *Hexagrammos decagrammus*, which was considerably higher than the other benthic fishes, and reflects systematic rather than environmental differences.

Growth rates presented here should be viewed as maximum estimates of yearly growth, since the winter growth rates would be necessarily lower. Temperature depression of metabolic rates and relatively lower winter food supply would both contribute to lower winter growth rates.

e. Population estimates of selected species

It was not possible to determine the population size of the majority of the benthic species because the sampling technique employed precluded capture-recapture population estimates. Consequently, the abundance of the benthic species can only be extrapolated from the results of the chemical collections. Table 8 presents estimates of population densities of abundant benthic species as determined by chemical samples. Since it was not possible to contain the effect of the chemical to the area of initial application, it is highly probable that the densities of fishes derived from these samples were overestimated. While the extent to which the chemical in-

Table 8. Estimates of the densities of benthic fishes together with estimates corrected for mortality outside the sampling area.

Species	Mean Density/m^2	Corrected Density
Hexagrammos decagrammus	0.86	0.64
Artedius harringtoni	4.00	3.00
Hemilepidotus hemilepidotus	0.38	0.29
Anoplarchus purpurescens	1.24	0.93
Jordania zonope	0.20	0.15
Phytichthys chirus	0.53	0.40
Hemilepidotus spinosus	0.17	0.13
Gobiesox maendricus	0.45	0.34
Nautichthys oculofasciatus	0.11	0.08
Xiphister atropurpureus	0.41	0.31
Synchirus gilli	0.42	0.32
Liparis florae	0.52	0.39
Liparis mucosus	0.21	0.16
Chirolophis nugator	0.80	0.60
Pholis schultzi	0.18	0.13
Apodichthys flavidus	0.11	0.08
Artedius lateralis	0.45	0.34
Artedius fenestralis	0.11	0.08
Oligocottus rimensis	0.17	0.13
Oligocottus snyderi	0.33	0.25
Bothragonus swani	0.33	0.25
Ascelichthys rhodorus	0.17	0.13
Blepsias cirrhosus	0.11	0.08
Enophrys bison	0.11	0.08
Hexagrammos lagocephalus	0.11	0.08

fluenced mortality outside the area was unknown, I have attempted to compensate for this by including density estimates which have been reduced by a correction factor of 25%. This correction factor is somewhat arbitrary, but probably extreme in relation to the method of application of the chemical and the exposure of the habitat (and consequent dilution of the chemical); the true population densities would probably lie between the two figures in the table.

Figures 11 and 12 illustrate population estimates of those species for which sufficient recapture data were available. Included on all graphs are eye-fitted curves reflecting the most probable asymptote of the estimates, based on previous tagging experience with these species. Differences in the types of plots are reflective not only of abundance, but also the nature of intraspecific association by individual species.

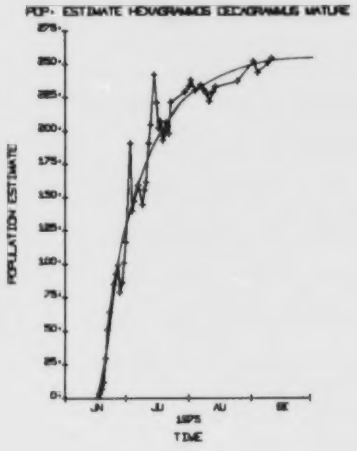
f. Diets of the fishes at the site

Table 9 presents a summary, by diet item, of the uses of kelp bed trophic resources by the fish community. There was almost complete segregation of diet item usage by benthic and neritic fishes. Considerable overlap existed between the dominant items in the stomachs of benthic fishes, especially cottids. A more detailed breakdown of diet item usage for those fishes examined is included in Appendix II.

Benthic crustaceans were the most highly utilized diet items by those fishes collected with the chemical. Gammarid and caprellid amphipods were most abundant in the diets of the twenty most common fishes. Other items in significant abundance were isopods, polychaetes and crabs. Juveniles of water column forms such as *Sebastes melanops* and

Figure 11. Population estimates of *Hexagrammos decagrammus* mature (a), *H. decagrammus* juvenile (b), and *H. legocephalus* (c). Included with the plots are eye-fitted curves showing the most probable asymptote of the estimates.

a.



b.

c.

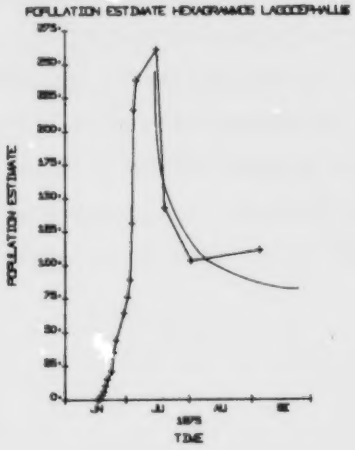
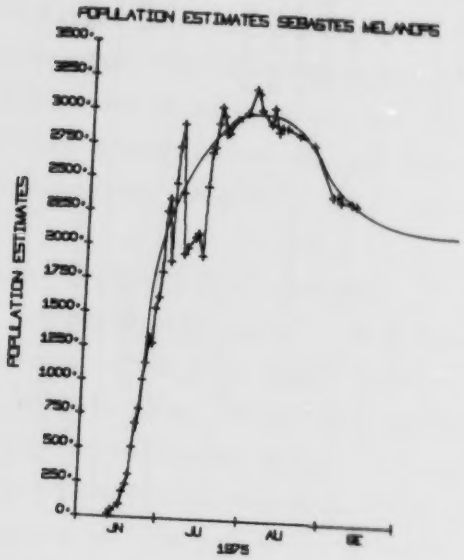


Figure 12. Population estimates of *Sebastes melanops* (a) and *Hemilepidotus hemilipidotus* (b). Included with the plots are eye-fitted curves showing the most probable asymptote of the estimates.

a.



b.

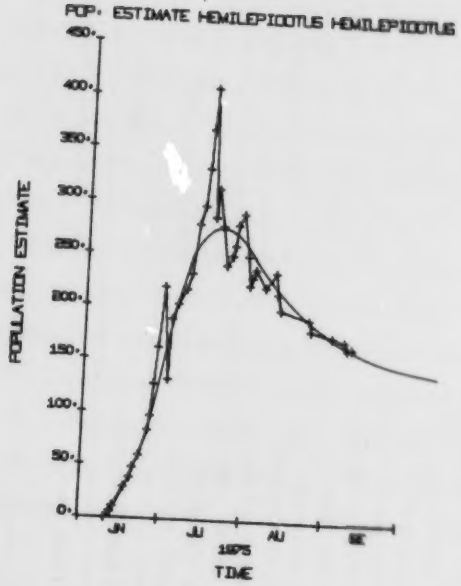


Table 9. Use of kelp bed trophic resources by fish species.

Gammarid amphipods	Caprellid amphipods	Gastropods	Isopods
Artedius harringtoni	Artedius harringtoni*	Embiotoca lateralis	Liparis mucosus
Embiotoca lateralis*	Hexagrammos decagrammus*		Synchirus gilli*
Synchirus gilli*	Oligocottus rimensis		Hexagrammos decagrammus
Hexagrammos decagrammus*	Hemilepidotus hemilepidotus*		Gobiesox maendricus*
Xiphister atropurpureus*	Phytichthys chirus*		Liparis florae*
Phytichthys chirus*			Pholis schultzi*
Artedius lateralis*			Cymatogaster aggregata*
Liparis florae*			
Anoplarchus purpurescens	Polychaetes	Crabs	Fishes
Ascelichthys rhodorus*			
Bothragonus swani*	Oligocottus rimensis	Hemilepidotus hemilepidotus*	Artedius lateralis*
Sebastes melanops	Xiphister atropurpureus	Hemile-idotus spinosus*	Ophiodon elongatus*
Oligocottus snyderi*	Chirolophis mugator*	Hexagrammos decagrammus*	Sebastes melanops*
Coryphoperus nicholsi	Phytichthys chirus		Merluccius productus*
Hemilepidotus hemilepidotus*	Anoplarchus purpurescens*		Squalus acanthias*
Jordania zonope*	Oligocottus snyderi*		
Hydrolagus colliei	Hydrolagus colliei*		
Lamellibranchs	Nauplii	Tunicates	Euphausiids
Rhacochilus vacca	Aulorhynchus flavidus	Anoplarchus purpurescens	Merluccius products
		Chirolophis nugator	

* dominant diet item

Aulorhynchus flavidus exploited benthic food sources, rather than the neritic sources found in the stomachs of larger specimens of these species.

The only species exploiting neritic food sources were larger *Sebastes melanops*, *Merluccius productus*, *Aulorhynchus flavidus* and *Engraulis mordax*. Food sources used by these three species were found in greatest abundance outside the main kelp bed rather than among the plants.

g. Structure of the fish community

Table 10 presents a classification of the species collected at the site based on diet analysis. The benthic samples were dominated by microcarnivores (fishes preying on small diet items), the majority of which exploited gammarid amphipods as their main diet item. The exception to this was *Artedius harringtoni*, which appeared to concentrate on caprellid amphipods. Only three of the smaller benthic forms could be considered as megacarnivores: *Artedius lateralis*, *Hemilepidotus hemilepidotus* and *Hemilepidotus spinosus* (Ayres), which showed crabs as the dominant item. Larger individuals of the benthic forms accessed correspondingly larger prey items, thereby passing into the megacarnivore class, e.g. *Hexagrammos decagrammus* and *Enophrys bison* (Girard).

The most abundant neritic forms obtained during the study, except for *Engraulis mordax*, were all piscivores. No resource partitioning of their diet, similar to that of the benthic species, was noted. The tubesnout, *Aulorhynchus flavidus*, was the only abundant planktivore resident in the kelp bed. The lingcod, *Ophiodon elongatus*, presented a special case, being a benthic form but using

Table 10. Classification of the fish species collected at the site based upon diet analysis.

Microcarnivores	Megacarnivores	Piscivores	Planktivores
Artedius harringtoni	Hexagrammos decagrammus	Sebastes melanops	Engraulis mordax
Synchirus gilli	Hemilepidotus hemilepidotus	Squalus acanthias	Clupea harengus pallasi
Xiphister atropurpureus	Hemilepidotus spinosus	Merluccius productus	Aulorhynchus flavidus
Phytichthys chirus	Artedius lateralis	Ophiodon elongatus	
Liparis florae	Hydrolagus colliei		
Anoplarchus purpurescens	Rhacochilus vacca		
Ascelichthys rhodorus	Hexagrammos lagocephalus		
Bothragonus swani	Scorpaenichthys marmoratus		
Oligocottus snyderi			
Coryphopterus nicholsi			
Hemilepidotus hemlepidotus			
Jordania zonope			
Gobiesox maendricus			
Liparis mucosus			
Embiotoca lateralis			
Cymatogaster aggregata			
Chirolophis nugator			
Oligocottus rimensis			
Pholis schultzi			
Hexagrammos decagrammus			

neritic fishes as a major diet item.

4. Experimental Canopy Harvest

The results of the limited canopy removal experiment were distinctly different for benthic and neritic fishes. In addition, the position within the kelp bed where the canopy was removed was an important determinant in the degree of influence this removal had on the fishes in the surrounding areas. Experimental harvest resulted in a decrease in the diversity of the chemical collections in the inner, middle and sheltered-type portions of the bed, but had insignificant effects on the benthic species diversity in the outer portions of the bed. Diversity indices and the corresponding information functions for the chemical collections are presented in Table 11. The simultaneous collections following the harvest are the only ones which are directly comparable because of the temporal separation of the other samples. The other sample results are included to illustrate the general difference in benthic species diversity following harvest. Benthic samples in the experimental and control areas were taken 17, 19 and 25 days after harvest at the inner, outer and middle plots, respectively.

The change in benthic diversity following harvest was a function both of the loss of species and a decrease in numbers of the remaining species. In both cases of decreased diversity, *Artedius harringtoni* remained the dominant benthic form. While the numbers of this species were decreased relative to control areas, they did not decrease as greatly as the remaining species in the harvested area. The proportionate importance of this species, therefore, increased following canopy removal.

The removal of the canopy of the 'outer' 100 m^2 plot did not significantly change the diversity index of the subsequent chemical sample, either in relation to previous samples or to simultaneous

Table 11. Evenness values, information content and diversity indices for the rotenone collections, by habitat type, illustrating the effects of canopy removal.

Habitat Type	Evenness (J)	Information (HN)	Diversity (H)
Sheltered	0.008	77.1	0.82
	0.006	124.1	0.88
	0.006	95.2	0.78
	0.008[1]	93.7[1]	0.91[1]
	0.014*	41.0*	0.76*
Middle	0.006	95.2	0.78
	0.005	81.8	0.66
	0.007[1]	118.0[1]	1.00[1]
	0.018*	23.9*	0.63*
Outer	0.014	30.5	0.61
	0.069	6.8	0.52
	0.006[1]	49.8[1]	0.53[1]
	0.010*	35.8*	0.56*

[1] - post-harvest control sample

* - post-harvest experimental sample

control area samples. In view of the exposed position of this plot, it might be expected that the species found in this area would be resistant to environmental perturbations. In addition, the diversity indices and information functions of the samples taken from other harvested areas are approximately equal to those of the exposed samples, implying some similarity to these disturbed areas.

The change in populations of the water column fihses in response to kelp harvesting was the opposite to that of the benthic fishes. Canopy removal at the outer plot decreased the abundance of fishes in the immediate area of the harvest, whereas canopy removal in the inner and middle plots resulted in an increase in the numbers of fish observed. Increases in the abundances of the fishes in these areas were primarily a function of changes in the number of smaller fishes present (Figure 9, p. 27, and Table 11).

DISCUSSION

1. Modification of the Habitat by Plants

The relatively large size of the Diana Island kelp bed in relation to other beds in Barkley Sound was largely attributable to the shallow slope of the bottom and the greater availability of substrate for plant attachment. The presence of satellite beds on shallower outcroppings around the main bed indicated that the outer horizontal limits of kelp were not determined by physical oceanographic factors alone. Inner limits of the beds were less well defined than outer limits and their position may have been the result of several factors, e.g. interspecific competition, wave stress or lack of sufficient water movement for physiological exchange. Vertical limits of plant distribution were similarly determined by both biological and physical factors such as photosynthetic compensation depth, grazing pressure from herbivores (notably the sea urchin, *Strongylocentrotus franciscanus* Agassiz) and temperature control of metabolic processes (Kitching, 1941; Neushul, 1976; Druehl, 1967; Pace, 1976).

The presence of plants in the water column at the site served to both modify and attenuate the force of waves striking the area of the bed. The abrupt change in bottom topography at the northeast edge of the bed dissipated the majority of the shock pressure of the waves approaching the kelp bed. The primary force on the plants over the relatively flat area behind the outside edge of the bed was the drag resulting from their form. The distribution of the plants in this section of the bed was approximately inverse to that of the shock pressure and friction components of the wave forces, although plant density changes probably occurred at a greater rate than that of the friction force. In comparison, the northwestern edge of the bed was less abrupt than the northern. This more gradual attenuation of the plants was probably accounted for by differences in the relative

slopes of the two areas and concomitant differences in the distribution of wave shock pressure on the plants. In spite of the fact that the plants constituted a compliant boundary, the stress on them would have been greater at this northwestern edge (Carstens, 1968; Reidel and Forstner, 1968). The modification of wave forces by plants created a distinctly different physical environment than existed in similar areas without kelp. While the kelp beds of Barkley Sound are seasonal in occurrence, it is reasonable to expect the presence of a fish fauna with some distinction from other nearshore areas, with regard to diversity and abundance of forms.

In addition to these changes in the dynamic environment created by the plants, a component of spatial heterogeneity exploited by the fishes was also added. This increase in heterogeneity was achieved through provision of interstitial spaces in the holdfasts of the plants and occlusion of the water column by the laminae. These areas were exploited by both neritic and benthic fishes.

2. Plant Reproductive Phenology and Dynamics

The results of the blade sampling program conducted during the study indicated that whatever method was considered to measure reproductive output (sori per blade, percent blade fertility, or area of reproductive tissue per blade), peak output occurred in late June - early July. There was some divergence in estimates of reproductive output for the remainder of the study when measured by percent fertility of the blades, or by the total area of reproductive tissue per blade. Since the percent fertility measure only considered the presence or absence of sori on the blades, without regard to their size or number, the measurement of the average area of reproductive tissue per blade was a more sensitive indicator of the actual effort expended by the plants on population reproduction.

3. The Fish Community at the Site

The species assemblage of benthic forms in the study *Nereocystis* bed was of a decidedly different character than that of *Macrocystis* beds in the same area. The latter is chiefly composed of blennioid forms such as *Xiphister atropurpureus* and *Pholis laeta* (Cope) (Druehl, Green and Leaman, unpublished data), whereas the *Nereocystis* bed at Diana Island was found to be dominated by cottid forms, chiefly *Artedius harringtoni*. Blennioid forms (e.g. *Anoplarchus purpurescens*) were present in collections from the sheltered and inner portions of the study *Nereocystis* bed; however, the higher proportion of blennioid forms in *Macrocystis* beds (six of the ten most common species) compared to *Nereocystis* beds (three of the ten most common species) is indicative of the higher degree of structural complexity of the holdfast and the understory plants in *Macrocystis* beds. Observations over one growing season in beds of both plants indicated that *Nereocystis* holdfasts were more closely adherent to the substrate than those of *Macrocystis*. In addition, the *Macrocystis* holdfasts of mature plants were generally of larger area than those of mature *Nereocystis* plants, at Diana Island. The potential habitat space available in the more complex *Macrocystis* holdfast, combined with the relatively more sheltered position of its beds, was thought to bed responsible for the higher proportion of blennioid species in *Macrocystis* beds.

Macrocystis beds support larger populations of neritic fish than do those of *Nereocystis* (this study; Leaman, 1976b). The larger degree of water column occlusion provided by *Macrocystis* plants would by itself probably account for the larger neritic fish populations in these beds, due to the increased shelter from visual predation. The observed distribution of *Sebastes melanops* juveniles in relation to exposure (Leaman, 1976b) may also contribute to the relatively greater numbers of this fish present in *Macrocystis* beds.

The benthic community of fishes at the Diana Island bed varied within the bed but was generally dominated by *Artedius harringtoni*, even in sheltered locations. All chemical collections showed communities to be composed largely of microcarnivores. The co-existence of a large number of individuals and species in the kelp bed is somewhat surprising in view of the fact that two pairs of the four most abundant fishes appeared to be directly competing for food resources. *Artedius harringtoni* and *Hexagrammos decagrammus* both heavily utilized caprellid amphipods, while *Anoplarchus purpurescens* and *Chirolophis nugator* competed for polychaetes and tunicates. No segregation of diet items between the four species was evident. The assumption must be made, therefore, that at the time this study was conducted, food was not a limiting factor in regulating the relative abundances of these competing species. The large number of species using amphipods as a food source and the low incidence of empty stomachs indicated that, in general, food was not a limiting resource during the period of this study.

The neritic community, by contrast, exhibited little diet overlap between species. In addition to the fact that no competition for primary diet items was evident, the neritic fishes also showed a much narrower total diet spectrum than their benthic counterparts.

The seasonal nature of the kelp beds of Barkley Sound obviously necessitates an alternate habitat for kelp bed species during the winter months. The present study did not examine the ecology of these species during the winter months and little is known of their seasonal dynamics. The only predators on benthic fishes present during the summer months were *Ophiodon elongatus* and, to a lesser degree, *Artedius lateralis*. The apparent abundance of food and the low numbers of predators evident infers that the period of residence within the kelp bed may not be the limiting one in terms of annual survival of fish. Almost all of the benthic forms spawn in the spring or early summer and survival over winter is crucial to population recruitment.

The relative densities of benthic fish species were, in part, determined by the degree of substrate relief. Samples from high relief areas showed both greater diversity and greater abundance than similar areas of low relief. This variation with regard to substrate relief was relatively less than the variation in diversity and abundance with regard to exposure. For example, the chemical samples of July 17 (0.88/124.1) and September 3 (0.91/93.7) (Table 11) were both sheltered areas, of low and high relief respectively. The difference between the diversity indices and information functions for these collections were small in relation to their differences with samples from exposed areas, such as that of August 16 (0.61/30.5). Quast (1968a) regarded the relief of the substrate as being the primary determinant of the abundance of fishes in the rocky inshore zone of California. While he did mention the influence of wave action on fish presence, he did not assign it any great importance in the determination of the distribution and abundance of species.

Limbaugh (1955) and Quast (1968a) distinguished different zones, or biotypes within California beds, such as canopy and mid-kelp areas. The shallowness of the Barkley Sound kelp beds precluded any distinctions of this type. Both of these authors regarded the kelp as extensions of the bottom substrate and thought the fish used the kelp as orientation points in the water column. The kelp bed fishes of Barkley Sound did not appear to use the kelp in this fashion since no change in vertical positioning occurred with changes in water clarity. The bottom relief of the kelp bed did not appear to affect the distribution of the neritic fishes since no correlation of abundance and bottom type was evident. The variation in abundance of neritic fishes within the kelp bed was largely accounted for by the variation in the density of kelp and the degree of exposure at the location. The presence or absence of kelp appeared to be of much greater importance in the determination of fish abundance at the Barkley Sound site than in California, although this may be entirely an artifact of the seasonality of the former.

a. Habitat utilization and association

Discussion of the utilization of kelp bed resources by fish species found in the beds, while yielding some understanding of the relationships of the fishes to the beds, should always be considered in light of the seasonality of the beds. Species which may be described as kelp associated forms cannot necessarily be described as kelp dependent, since it is known that they persist in the absence of kelp. The crucial point to examine in assessing the importance of the kelp bed to these fishes is not whether they are dependent upon it *per se*, but whether the bed contributes measurably to the maintenance of existing populations. The determination of this will then aid in the assessment of any possible detrimental effects associated with kelp harvesting.

The distinction of the use of definite segments of the habitat by species was slight. The benchic species, except for the blennioid forms, used all segments of the bed. As noted previously, the relief of the bottom substrate was one of the determinants of community diversity and abundance. Blennioid species were found in greatest abundance in the more sheltered areas of the bed, regions that were also more structurally complex due to the increased floral abundance in these areas. None of the benthic species could be directly tied to the kelp plants, but several species evidenced positive (though unquantified) associations. *Liparis* spp. were observed many times among the stipes and blades of the plants. Additionally, the blades of the plants may have served as a substrate for larval settlement, as very small (< 15 mm) liparids were noted on the blades whenever observations were made in the canopy. *Synchirus gilli* was also noted in the canopy regions, although not on the blades, as with the liparids, but among

bundles of stipes. Only *Phytichthys chirus*, of the blennioids, was noted above the substrate. This species adopted the same habits as *S. gilli* but only 1 - 1.5 m above the holdfasts of the plants.

The presence of large numbers of hydroid colonies, primarily *Plumlaria* spp. and *Aglaophenia* sp., was beneficial in that numerous caprellid amphipods of the genus *Caprella* fed upon these hydroids and were, in turn, fed upon by a variety of benthic fishes. These benthic fishes may not have been associated with the *Nereocystis* plants themselves, but the environmental modifications created by kelp in the water column led to the provision of advantageous feeding and habitat conditions.

The relationship of neritic fishes to the kelp bed was more well defined than for benthic fishes. *Aulorhynchus flavidus* may be directly tied to the *Nereocystis* plants because it deposited its eggs on their pneumatocysts. None of the other neritic species used the plants directly, but the distribution of *Sebastes melanops* within the bed, when considered in light of previous work in *Macrocystis* beds, inferred that a similar shelter-oriented relationship existed in *Nereocystis* beds. The differences in the distribution of adults and juveniles of the embiotocid genera within the kelp bed also suggested the same type of relationship.

In summary, the associations between those fishes studied and the kelp bed appeared to be primarily indirect, except for a few specialized forms. This lack of direct relationship does not infer that the kelp bed is an unimportant factor in the ecology of those species frequenting it. At the simplest level, the differential abundance of forms inside and outside the bed infers the provision of

a more optimal habitat, be it through either primary or secondary factors. At a more complex level, the species linkages within the bed evidence a co-evolutionary history of some duration. Indeed, the benthic species exhibited a degree of resource partitioning (utilization of different components of the same resource in order to minimize competition), both with regard to food sources and habitat space. While this study did not attempt to quantify this partitioning or the degree of niche overlap, it is obvious that the interrelationships of the species within the bed were not primarily opportunistic, as is the case with some communities based on seasonal resources.

4. Experimental Harvesting

The response of the neritic and benthic fishes to limited canopy removal were qualitatively and quantitatively dependent upon the position of removal within the bed. In areas of the middle and inner segments of the bed, which had relatively high benthic species diversity and abundance, canopy removal degraded both these characteristics. By contrast, the neritic fishes were more abundant in these areas following canopy removal. In the outer segments of the bed, where benthic diversity and abundance were lower than in the inner segments, canopy removal appeared to have no effect on benthic fish species and negative effects on neritic fishes. The fact that the diversity indices and the information functions of the middle and inner harvested plots were very similar to the observed values of the outer plot suggested that there may be a basic 'unit' (in terms of diversity and abundance) which is common to disturbed or stress environments. If one uses the observed abundances of fishes as indicators of optimal environments, then a generalization regarding the effects of harvesting might be that modifications of sub-

optimal environments create little change in resident populations, while modifications of optimal environments produce negative changes. The positive effect of canopy removal on inner neritic fishes was apparently a result of the provision of a more optimal environment by such removal. The clearing of a space in the centre of the bed allowed planktonic food organisms to aggregate and thus created a feeding environment which did not have as much associated predation potential as a similar feeding environment outside the kelp bed. There may be an upper limit to the size that such clearings can be and still produce positive effects; further work would be needed to determine these limits. While the time frame over which canopy removal maintains an effect on resident fishes is unknown, the results of the benthic sampling indicated that these effects persist for at least 25 days following canopy removal.

Miller and Geibel (1973) examined the effects of canopy removal on fishes in central California kelp beds and concluded, as did Limbaugh (1955), that canopy removal did not adversely affect the abundance of adult species in *Macrocystis pyrifera* beds. The presence of large numbers of juvenile rockfish in these beds is analogous to the situation in Barkley Sound. These authors noted that juveniles moved down in the water column after canopy removal rather than horizontally into uncut sections. Their data also indicated that the juveniles may have moved into the cut canopy regions as well, although not as abundantly as those moving downward. Large variation in daily sightings of fish hampered the assessment of canopy removal effects in their study. In addition, while they removed canopy on four occasions, they report the effects on fish for only one day following harvest. Miller and Geibel also considered their removal experiments of small scale in relation to the amount of remaining uncut canopy, similar to the present study.

A separate consideration regarding the harvest of kelp plants pertains to the effects of such harvesting on associated and transient species. Negative effects on resident species are confined

to local populations, but effects on transient species may be spread over all individuals who use the region of the kelp bed. Any positive or negative effects may potentially affect a large segment of a regional or spawning population. For this reason, it becomes imperative to ascertain the utilization of kelp bed resources by large transient populations, especially with regard to commercial species such as herring and salmon.

5. Implications of the Study

1) Canopy removal has definite quantifiable effects, in terms of diversity and abundance of species, on both neritic and benthic fish communities. The qualitative and quantitative nature of these effects may be, in part, determined by the position within the bed where the canopy is removed.
2) Benthic and neritic fish species appear to be ecologically distinct. Perturbation of a community of one of these groups will not necessarily have a simultaneous or subsequent effect on the other.
3) The influence of perturbations of the kelp bed ecosystem may extend beyond the boundaries of the kelp bed through effects on associated and transient fish species. Local changes may thus have extended influences.

6. Future Research Needs

1) The interrelationships of transient and associated fish species with kelp beds should be examined; specifically with a view to determining the extent to which local changes in the kelp bed affect wide ranging transient populations. Clupeids and salmonids are the most important of those populations to be examined.

2) The time over which the removal of kelp canopy affects fish populations should be determined to ascertain whether these effects are short or long term and if mitigation is possible.

3) The optimal size of the harvested area should be determined with a view to obtaining an optimal balance between any positive and negative effects of harvesting.

4) The optimal time of harvesting should be determined in order to minimize perturbations of spawning and recruitment to fish populations and of the reproduction of the plants.

5) The ecology of local fish populations which are related to the kelp bed during the kelp growing season should be examined during periods of kelp absence so that the relative importance of the kelp bed in the fish life cycles can be determined.

CONCLUSIONS

1) The modification of the physical environment by the plants, particularly with regard to wave stress, creates a habitat within which the abundance and diversity of species increases over non-kelp areas.
2) The plants expended the majority of their reproductive effort by the end of July, as determined by measurement of the total reproductive tissue per blade.
3) The majority of fish species within the kelp bed are not directly related to the plants, neither feeding nor living on them. Indirect relationships may be with regard to feeding, shelter or reproduction.
4) Fish species found in kelp beds may be resident, associated or transient, depending on the intimacy of their relationship to the kelp bed.
5) In general, the distribution of benthic (bottom) fishes within the kelp bed is not related to plant density; rather, fishes are distributed along a wave exposure gradient, with lowest diversity and abundance occurring at the most exposed locations within the bed. Juvenile neritic (water column) fishes, except for *Sebastes melanops*, appear to be positively correlated with kelp density. Some vertical and horizontal partitioning of the habitat by size was evident in some fishes. *S. melanops* appears to be associated with the seaward edge of the bed in a manner similar to its relationship with *Macrocystis integrifolia* beds.
6) Benthic fish species feed upon diet items which are abundant within the kelp bed. Neritic fishes generally feed upon neritic food sources, but it is not known whether these food sources are positively correlated with kelp

beds alone. One neritic species, *Sebastes melanops*, feeds on juvenile herring which are only found in abundance outside the kelp bed.

7) Experimental canopy removal suggests that removal has negative effects on abundance and diversity of fishes in their optimal environments and that this effect is noticeably less, or negligible, as canopy is removed from environments which are sub-optimal for the fishes considered. Additionally, canopy removal can have simultaneous negative and positive effects on benthic and neritic fish species.

These conclusions apply to the work conducted during this study and, while they reflect the general features of the ecology of fishes in *Nereocystis* beds, different environmental conditions at other locations and times will affect the applicability of these conclusions at these locations.

RECOMMENDATIONS

Based on the results of the present study and with regard to the Barkley Sound kelp bed, the following recommendations can be made:

1) A sound policy for the harvesting of kelp cannot be established without assessing the effects of such harvesting on resident, associated and transient fish species, especially clupeids and salmonids. Harvesting should be undertaken on a limited scale until such information is available. Such harvesting as is permitted should be conducted in conjunction with experiments designed to assess the effects of harvesting on kelp bed fish species. Effects of harvesting may be highly site-specific.
2) While my limited kelp harvesting had a negative effect on benthic fish diversity when the middle and inner segments of the bed were harvested, the removal of the outer segments would probably have more serious consequences on resident fishes. This is due to the displacement of neritic fish species and the alteration of the wave exposure gradient within the bed, and its associated effects upon the benthic species.

SUMMARY

The interrelationships of the fish community in a Barkley Sound *Nereocystis* bed were examined with regard to the utilization of kelp bed resources and the alterations of this community resulting from experimental canopy removal. The diversity and abundance of fish species within the kelp bed is increased over non-kelp areas, primarily due to the modification of the physical environment by the kelp plants. The majority of the resident fishes in the kelp bed are not directly related to the plants. Experimental canopy removal at the outer segments of the bed had negative effects on neritic (water column) fishes and negligible effects on benthic (bottom) fishes. In contrast, canopy removal at the middle and inner segments of the bed had positive effects on neritic fishes and negative effects on benthic fishes. Benthic and neritic fish groups do not appear to be dependent upon each other; that is, modification of a community of one of these groups does not necessarily affect the other. There were definite quantifiable effects of canopy removal on resident kelp bed species and, while none of these species are of direct commercial importance, large numbers of associated and transient species are found around the periphery of kelp beds, especially juvenile herring and salmon. A sound kelp management policy cannot be formulated until the effects of kelp harvesting on these commercial species are determined.

Harvesting of kelp will affect resident fish species to the least degree if the middle segments of the bed are removed in a series of patches, rather than the more accessible seaward segments.

LITERATURE CITED

Alevizon, W.S., 1975. Comparative feeding ecology of a kelp bed embiotocid (*Embiotoca lateralis*). Copeia 1975(4): 608-615.

Bray, R.N. and A.W. Ebeling, 1975. Food, activity and habitat of three 'picker' type microcarnivorous fishes in the kelp forests off Santa Barbara, California. Fish. Bull. 73(4): 815-829.

Brillouin, L., 1960. Science and information theory (2nd edition). Academic Press, N.Y.

Carstens, T., 1968. Wave forces on boundaries and submerged bodies. Sarsia 34: 37-63.

Chapman, D.G., 1954. The estimation of biological populations. Ann. Math. Stat. 25: 1-15.

Davies, David H., 1958. The relationship between sportfishing in the kelp beds and the harvesting of kelp off the coast of California. University of California Institute of Marine Resources Ref. 58-4. 56 pp.

Druehl, L.D., 1967. Vertical distribution of some benthic marine algae in a British Columbia inlet, as related to some environmental factors. J. Fish. Res. Bd. Can. 24(1): 33-46.

Ebeling, A.W., R. Larson, W. Alevizon and F.A. DeWitt Jr., 1971. Fishes of the Santa Barbara kelp forest. (Abstract) University Press, University of Southern California. 1 p.

Feder, H.M., C.H. Turner and Conrad Limbaugh, 1974. Observations on fishes associated with kelp beds in southern California. Calif. Dept. Fish and Game. Fish. Bull 160. 144 pp.

Follett, W.I., D. Gotshall and J.G. Smith, 1960. Northerly occurrences of the scorpid fish, *Medialuna californiensis* (Steindachner), with meristic data, life history notes and discussion of the fisheries. Cal. Fish and Game 46(2): 165-175.

Gotshall, D.W., J.G. Smith and A. Holbert, 1965. Food of the blue rockfish, *Sebastodes mystinus*. Cal. Fish and Game 51(3): 147-162.

Hart, J.L., 1973. Pacific fishes of Canada. Fish. Res. Board Can., Bull. 180. 740 pp.

Kitching, J.A., 1941. Studies in sublittoral ecology. III. *Laminaria* forest on the west coast of Scotland; a study of zonation in relation to wave action and illumination. Biol. Bull., Woods Hole, vol. 80: 324-327.

Leaman, B.M., 1976a. An inexpensive tag for short-term visual tracking studies. J. Fish. Res. Board Can. 33(6): 1628-1629.

_____ 1976b. MS. The association between the black rockfish (*Sebastes melanops* Girard) and beds of the giant kelp (*Macrocystis integrifolia* Bory) in Barkley Sound, British Columbia. M. Sc. Thesis. Univ. of British Columbia, 109 pp.

Limbaugh, Conrad, 1955. Fish life in the kelp beds and the effect of kelp harvesting. University of California Institute of Marine Resources IMR Ref. 55-9. 158 pp.

_____ 1961. Life history and ecological notes on the black croaker. Cal. Fish and Game 47(2): 163-174.

_____ 1962. Life history and ecological notes on tubenose, *Aulorhynchus flavidus*, a hemibranch fish of western North America. Copeia 1962(3): 549-555.

Miller, David J. and J.J. Geibel, 1973. Summary of blue rockfish and lingcod life histories; a reef ecology study; and giant kelp, *Macrocystis pyrifera*, experiments in Monterey Bay, California. Calif. Dept. Fish and Game. Fish. Bull. 158. 137 pp.

Neushul, Michael, 1967. Studies of subtidal marine vegetation in western Washington. Ecology 48(1): 83-94.

O'Connell, C.P., 1953. Life history of the cabezon. Calif. Dept. Fish and Game. Fish. Bull. 93: 1-76.

Pace, D.R., 1976. MS. Ph.D. Thesis. Simon Fraser University.

Paine, R.T., 1971. The measurement and application of the calorie to ecological problems. Ann. Rev. Ecol. System. Vol. 2: 145-164.

Phillips, J.R., 1957. A review of the rockfishes of California (family Scorpaenidae). Calif. Dept. Fish and Game. Fish. Bull. 104: 1-158.

Quast, J.C., 1968a. Some physical aspects of the inshore environment, particularly as it affects kelp bed fishes. In: Utilization of kelp bed resources in southern California. Calif. Dept. Fish and Game. Fish. Bull. 139: 25-34.

_____ 1968b. Fish and fauna of the rocky inshore zone. Calif. Dept. Fish and Game. Fish. Bull. 139: 35-56.

Reidel, R. and H. Forstner, 1968. The microstructure of water movement in the benthos. Sarsia 34: 163-168 (in German).

Roedel, P.M., 1953. Common ocean fishes of the California coast. Calif. Dept. Fish and Game. Fish. Bull. 91: 1-84.

Skogsberg, Tage, 1952. The fishes of the family Sciaenidae (Croakers) of California. Calif. Dept. Fish and Game. Fish. Bull. 54: 1-62.

Turner, Charles H. and E.E. Ebert, 1962. The nesting of *Chromis punctipinnis* (Cooper) and a description of their eggs and larvae. Cal. Fish and Game 48(4): 243-248.

Wales, J.H., 1952. Life history of the blue rockfish, *Sebastes mystinus*. Calif. Dept. Fish and Game. Fish. Bull. 37: 1-22.

Whyte, J.N.C. and J.R. Englar, 1974. Commercial kelp drying operation at Masset, 1973. Fish. Res. Board Can. Tech. Rep. No. 453. 30 pp.

Williams, George C. and Doris C. Williams, 1955. Observations on the feeding of the opaleye, *Girella nigricans*. California Fish and Game 41(3): 203-208.

APPENDICES

I. Methods and Materials

II. Ecological Notes on Fishes Common to the Study Site

III. Additional Studies Conducted at Port Hardy, British Columbia

APPENDIX I

Methods and Materials

1. The Site

The site was located in Barkley Sound at position 48° 51.1' W, 125° 11.1' N, on the north side of Diana Island. The total area of the site was calculated from an aerial photograph obtained through the British Columbia Department of Lands, Forests and Water Resources (BC 7238-284). The area of the site occupied by the kelp bed was estimated from subsequent low-level photographs.

Topography of the bottom at the site was determined by hand soundings; these data were used to construct a bathymetric map of the site.

Wave exposure at the site was qualitatively estimated from *in situ* observations and correlations with the distribution of organisms, other than fish, whose distribution in relation to wave exposure was well established. A map was constructed on the basis of these observations which reflected the relative degrees of exposure at various locations in the kelp bed, rather than the absolute values of shock pressure and friction force.

Substrate observations were made with a view to determining the distribution of rock capable of supporting kelp sporophyte growth, without regard to the geological nature of the rock itself.

The general distribution of the major phaeophyte algae of the understory was recorded on initial observation dives. In addition, more specific observations were made at the three plots established for experimental canopy removal.

2. The Plant

The distribution of *Nereocystis* plants was calculated using sample counts from 1 m^2 quadrats placed at random within the 100 m^2 experimental plots. Portable quadrats made of PVC piping were assembled around the plants and all stipes inside the quadrat were

counted. In addition, the total number of plants contained within the 100 m^2 plots were enumerated during the harvesting operation. Morphometric measurements of the plants were obtained by enclosing a 1 m^2 area with the PVC quadrats and harvesting all the entire plants. Plants were brought to the dive boat and measured in the field.

Reproductive phenology of the plants was monitored via 50-blade samples taken at random in the bed, approximately every ten days. Blades were returned from the field and measured in the laboratory; blades were measured to the nearest cm and sori to the nearest mm. Sori were measured as rectangles and area was calculated from length and width measurements. Sori which were translucent were assumed to be immature. Dark brown sori with translucent areas at the margins were assumed, on the basis of initial cytological examination, to be mature. Fertility of the blades was taken as the presence or absence of sori without regard to number. Total reproductive tissue was calculated as the mean area of the sori times the total number of sori found on all blades.

3. The Fishes

Fish were obtained for tagging, diet and age analysis using monofilament gillnets of sizes varying from 1.27 - 10.16 cm (wet, stretched) mesh sizes. Nets (3 - 6) were set in L-shaped or T-shaped patterns at random and specific locations within and around the kelp bed. Nets were set approximately one hour before sunset and retrieved at sunrise to maximize the number of live fish recovered. Specimens recovered dead in the nets were frozen upon return from the field and analyzed at a later time.

Benthic samples were obtained using a commercial preparation of rotenone (Chem Fish Collector, Blue Spruce International). The chemical was applied to measured areas with plastic 'squeeze' bot-

tles. The majority of the samples were obtained with an application area of nine m^2; this size area was chosen after initial samples indicated that four m^2 samples were subject to high variability and 16 m^2 samples were logistically intractable with regard to total sample recovery. Fish were collected by divers using long-handled scoop nets with deep mesh bags that could be gathered to prevent escape of specimens. Samples were fixed in buffered, 10% formalin in the field and transferred to 37.5% isopropyl alcohol after 24 hours.

Net-caught specimens recovered alive were tagged with nylon anchor tags (Floy Tag Mfg., FD-67) attached to numbered, coloured tubing. Some fish were also tagged with a fluorescein tag (Leaman, 1976a) for movement studies.

Population estimates of net-caught fish were generated using Chapman's (1954) formula for an unbiased Schnabel capture - recapture estimate. Density of benthic fishes was extrapolated from the quantitative chemical collections and pro-rated 25% to account for mortalities outside the application area.

In the examination of the diets of kelp bed fishes, only the contents of the stomachs were analyzed because intestinal contents were generally unrecognizable or impossible to totally recover. Stomachs were removed from the animal, fullness estimated and the contents emptied into a finger bowl for microscopic examination. Contents were scored by percent occurrence and by percent dominance. A dominant item was any item which represented $\geq$ 50% of the total volume of the contents, estimated by eye. The dominant item selected on this basis yielded a general estimation of the major components of the fish's diet. Volume was the basic criterion used because an analysis based on frequency of occurrences alone confers equal statistical weight to all occurrences of an item, without regard to the quantity of the item in the stomach. A volume based analysis has the additional advantage of incorpor-

ating some aspects of the energy contribution of diet items, although results regarding energy input through diet items must be interpreted cautiously if no data are available concerning caloric content, nutrient requirements or assimilation efficiency (Paine, 1971). Specimens whose stomachs contained no clearly dominant item or whose contents were too digested to determine dominance, were assigned no dominance.

In situ observations of fish distribution and abundance were made while conducting underwater sweeps (using SCUBA) and recorded on slates carried by divers. Observations attempted to encompass all aspects of the diel activities of the fishes as well as seasonal aspects of their biology.

Experimental canopy removal took place on a rising tide and the cut sections of the plants were permitted to float away. Three 100 m^2 plots were established at the outer, middle and inner sections of the bed. Plants were cut by hand to a depth of 1.52 m below mean sea level. Post-harvest samples and observations were made at varying intervals following harvest.

APPENDIX II

Ecological Notes on Fishes Common to the Study Site

Due to the limited amount of research conducted on littoral fishes common to the British Columbia coast, there is little information available on the ecology of these species. The descriptive notes concerning common kelp bed fishes are presented in this Appendix primarily to increase the amount of published information on these forms. Methodology used in obtaining this information is presented in Appendix I. Some familiarity with the common benthic invertebrates by the reader is assumed. Water column forms are not treated in this Appendix because their ecology is somewhat better known than these benthic forms. Quantitative data on sex ratios, growth, sizes and densities are included where sample sizes were sufficiently large. The remaining species are treated in varying detail as information was available and may be restricted to any, or all, of distribution, feeding or behaviour. The interested reader is directed to a publication by Feder et al. (1974) for a comparison with California kelp bed fishes, although this work was directed primarily at neritic fishes.

All sizes referred to are in millimetres; mean sizes are extremes of collection means and are bounded by two standard errors of the mean. Densities of fish refer only to areas where they were collected and are based upon nine-m^2 sample sizes.

1. *Artedius harringtoni*

Number collected: 485

Density: 3.0 - 4.0/m^2

Means: 42.5 ± 10.5 - 66.6 ± 4.2 mm

Sex ratio (/): 484:1

Size range: 22.5 - 86.8 mm

Estimated annual growth: 45 mm

a. Diet

Primarily caprellids (42% dominance) and gammarids (29% dom.); also isopods, shrimp, crabs, fish (perciform) and polychaetes. 13.6% empty. Species identified in the diet:

Caprella mendax	*Photis californica*
C. laeviscula	*Parapleustes pugettensis*
C. equilibra	*Podocerus* sp.
C. natalensis	*Photis bifurcata*
C. incisa	*Erichtonius brasiliensis*
C. gracilior	*Lembos* sp.
C. ferrea	*Heptacarpus* sp.

Metacaprella kennerlyi

b. Notes

Common throughout the kelp bed, with no apparent mode of abundance. Samples outside the kelp bed show it to be the most common form in these areas as well. The species does not appear to have any specialized habitat requirements. It is generally obvious and aggressive, being attracted to any disturbance in its vicinity. The highly distorted sex ratio of the kelp bed samples is of some interest. Collections outside the bed showed the same ratio; the lone male collected was captured in the outer segment of the kelp bed. It is possible that a bathymetric segregation of the sexes exists in this species, similar to that of some clinids; however, the ratio observed at the site is extreme even for a segregation of this type. Seasonal segregation of sexes is also distinctly possible. Gravid females noted at sizes > 53.5 mm, which were probably age-group I fish.

2. *Anoplarchus purpurescens*

Number collected: 115
Density: 0.93 - 1.25/m^2
Mean sizes: 61.5 ± 18.7 - 90.1 ± 3.1 mm
Sex ratio (/): 1.22:1.0

Size range: 38.7 - 115.2 mm
Estimated annual growth: 50 mm/yr

a. Diet

Primarily polychaetes (42.3% dom.), tunicates (30.8% dom.) and gammarids (23.1% dom.). 21.2% empty. Polychaetes in the diet are sabellid branchial and feeding appendages. Amphipods are *Photis* spp. and *Parapleustes pugettensis*. Tunicates are colonial tunicates found abundantly throughout the kelp bed. Hart (1973) lists green algae as a primary food item; however, it is probable that its presence in the gut represents incidental ingestion only.

b. Notes

Species is found more abundantly in the less exposed segments of the kelp bed, generally with high relief bottom. Often found in holdfasts of *Nereocystis* and understory plants. This form is not generally observed in the field, it is believed to spend the majority of its time concealed. 8% of total numbers collected outside the kelp bed. Considerable colour variation in this species with the younger forms often having solid black bodies and the dorsal fin area covered with closely set patterns of light-coloured diamond shapes.

3. *Hexagrammos decagrammus*

Number collected: 100 (benthic)
Size range: 63.1 - 141.2 mm
Density: 0.64 - 0.86/m^2
Estimated annual growth: 150 - 200 mm/yr
Mean sizes: 86.3 ± 5.3 - 127.3 ± 10.3 mm
Sex ratio (/): 2.1:1.0

a. Diet

While it is a generalist by occurrence of diet items (pycnogonids, gastropods, dipteran larvae), two items make up almost the entire volume of the stomach contents of the smaller specimens (55.2% caprellids, 41.4% gammarids). The 101-200 mm fish also eat isopods (57% dominance). Larger specimens (201 - 700 mm) are generalists exhibiting slight dominance of crabs. Species identified in the diet:

Caprella gracilior	*Lebbeus lagunae*
C. laeviscula	*Heptacarpus*
C. ferrea	*Pachycheles*
C. incisa	*Cancer gracilis*
C. equilibra	*Cancer oregonensis*
Parapleustes pugettensis	*Pagurus*
Erichtonius brasiliensis	*Oregonia gracilis*
Photis	*Loxorhynchus crispatus*
Podocerus	*Petrolisthes eriomerus*
Metaphoxis	*Haliotis kamschatkana*
Artedius lateralis	*Synchirus gilli*

b. Notes

The smaller (30 - 150 mm) specimens of this species are highly territorial and very active. Territorial defences appear to be directed primarily at conspecifics of the same size class. Territories may overlap several *Jordania zonope* territories. Conspicuous in the field, being the largest of the benthic forms encountered in the kelp bed. Most abundant at the seaward edge of the bed, larger (200 - 700 mm) forms being of the associated class. Smaller forms may be preyed upon by *Ophiodon elongatus*, as one attach was noted. Sexes are distinctly dichromatic, although this is not evident until the onset of sexual maturity (200 mm). Based on tagging studies, species appears to be resident in a given area for at least two years. Spawning in the adults begins in mid-September in Barkley Sound.

4. *Chirolophis nugator*

Number collected: 98
Density: 0.6 - 0.8/m^2
Mean sizes: 68.7 ± 14.7 - 87.6 ± 18.8 mm
Sex ratio (/): 0.64:1.0
Size range: 47.0 - 127.0 mm
Estimated annual growth: 50 mm

a. Diet

Diet consists primarily of polychaetes (79.2% dom.) and nemerteans (14.2% dom.). 25.9% empty. Species identified in the diet:

Parapleustes pugettensis
Spirorbis fans
Metacaprella kennerlyi
Erichtonius brasiliensis
Heptacarpus sp.

b. Notes

The distribution of the species, in common with the majority of the blennioids, is relief oriented. Generally found in high relief areas without regard to exposure conditions, approximately 10% of sample from middle and inner locations. 5 - 7% of sample outside the kelp bed. Sexual maturity probably achieved in the second year as females with fully developed ovaries were noted only in specimens > 80 mm TL. Rarely observed in the field due to the habits of the species. Found both in rock burrows and holdfasts of kelp plants.

5. *Hemilepidotus hemilepidotus*

Number collected: 96
Density: 0.29 - 0.38/m^2
Size range: 41.4 - 196.0 mm
Estimated annual growth: 145(101 - 200 mm); 58(201 - 300 mm)
Mean sizes: 50.7 ± 3.3 - 111.5 ± 64.8 mm
Sex ratio (/): 0.83:1.0

a. Diet

Smallest size class (0 - 100 mm) showed no significant difference in dominant items although gammarids and caprellids are more abundant than other items. Larger size classes showed equal utilization of crabs and caprellids. Although hydroids and algae show 25% occurrence in the larger size class fish, their presence is almost certainly incidental to directed feeding on other items. 6.3% empty. Species identified in the diet:

Calliostoma sp.
Tegula pulligo
Metacaprella kennerlyi
M. anomala
Caprella equilibra
C. incisa
C. natalensis
Pachycheles rudis
Erichtonius brasiliensis
Artedius lateralis
Loxorhynchus crispatus
Cancer oregonensis
Caprella mendax
C. ferrea
C. laeviscula

b. Notes

Largest of the resident cottids. Appears to have either very restricted range of movement or a base of activity to which it may return. Larger (200 - 300 mm) forms may be found consistently at one location over a period of months. No apparent mode of abundance within the bed - generally 7-10% of samples taken inside as well as outside the kelp bed. Cryptically coloured to a marked degree and highly variable in base colour. Commonly sighted in the field, not highly active form. While its limited range may infer a certain territoriality, defenses of territory were never observed.

6. *Jordania zonope*

Number collected: 80
Density: 0.15 - 0.20/m^2
Mean sizes: 49.6 ± 3.1 - 67.6 ± 7.2 mm
Sex ratio (/): 0.6:1.0
Size range: 37.9 - 91.1 mm
Estimated annual growth: 40 mm

a. Diet

Stomach contents primarily gammarids (78% dom.), polychaetes (11% dom.) and shrimp (11% dom.). Species identified in the diet:

Parapleustes pugettensis *Erichtonius brasiliensis*
Photis californica

b. Notes

This species might best be classified as an associated form since it is found primarily at the seaward edge of the kelp bed and outside it. It was the most abundant form collected outside the kelp bed (37% of samples). Often encountered in the field, it is highly territorial and aggressive, defending its territory (0.25 - 0.5 m^2) from both conspecifics and other species, notably *Artedius harringtoni*. Have observed it being preyed upon by *Artedius lateralis* in the field. Common in exposed environments, evidence for two age-groups indicates growth rate somewhat below that of most kelp bed cottids. Often noted on steeply sloping or vertical rock faces.

7. *Phytichthys chirus*

Number collected: 59
Density: 0.4 - 0.53/m^2
Mean sizes: 68.2 ± 11.5 - 112.9 ± 20.3 mm
Sex ratio (/): 0.55:1.0

Size range: 44.2 - 168.5 mm
Estimated annual growth: 55 mm

a. Diet

Gut contents of smallest fish (0 - 100 mm) dominated by gammarids (90.5% dom.) with polychaetes contributing slightly (10%). 101 - 200 mm fish had more diverse diet: 57% dominance gammarids, 28.6% caprellids, 14.3% crabs, 14.3% polychaetes. 0% and 11% empty stomachs for the two size classes respectively. Species identified in the diet:

Pagurus sp.
Erichtonius brasiliensis
Parapleustes pugettensis
Caprella equilibra
C. laeviscula
Photis sp.

b. Notes

Species is most abundant in high relief, sheltered areas of the bed where it is generally 8 - 12% of the sample. Not restricted to the kelp bed, though uncommon outside. When observed in the field, it is generally sitting vertically in twisted bundles of *Nereocystis* stipes. Several colour morphs of this species visible ranging from bright green to reddish-brown. It is not known if individuals can control their colour to any great degree; however, if this control is present it is probably not neural in nature, as specimens do not undergo abrupt colour changes after death.

8. *Liparis florae*

Number collected: 56
Size range: 19.0 - 117.2 mm
Density: 0.39 - 0.52/m^2
Mean sizes: 31.1 ± 6.8 - 68.9 ± 26.4 mm
Sex ratio (/): 1.0:1.0

a. Diet

Due to the nature of the feeding of this species, gut contents are often impossible to identify past the phylum level; therefore, the dominant item in this species was crustacean remains (52.2%). Of those contents which were identifiable, 17.4% were gammarids, 13% isopods (aselottid) and 8.7% gastropods (prosobranchs). 19.2% empty. Species identified in the diet:

Photis californica *Caprella incisa*
Caprella equilibra

b. Notes

Most abundant in exposed environments of either high relief or with abundant vegetation present. One of the most common species outside the kelp bed where it formed 10 - 15% of the samples. In the outside collections it was abundant in 'beds' of *Calliarthron regenerans*, *Botryoglossom farlowianum* and *Laurencia spectablis*. Inside the bed, common in holdfasts of *Nereocystis* and understory kelps. Based on limited observations, this species appeared to be most active nocturnally and could often be found attached by its ventral disc to blades of *Laminaria* spp. moving in the surge. Sexual maturity appears to be attained very quickly with growth. Fish > 30 mm had identifiable gonads, whereas fish < 28 mm were not sexually distinguishable. The blades of *Nereocystis* may serve as substrate for larval settlement as small juveniles (< 15 mm) could always be found in the canopy blades.

9. *Gobiesox maendricus*

Number collected: 52
Size range: 17.9 - 80.4 mm
Density: 0.34 - 3.45/m^2
Mean sizes: 34.7 ± 1.6 - 55.0 ± 6.0 mm
Sex ratio (/): 1.0:1.0

a. Diet

Species appears to be a generalist benthic feeder. Percentages of diet item dominance were isopods (26.7%, asellotid), crustacean remains (26.7%), polyplacophorans (20.0%), polychaetes and caprellids (6.7% each). Due to the manner of feeding, gut contents were generally unrecognizable; hence the percentage dominance of crustacean remains. Species identified in the diet:

Tonicella lineata *Artedius lateralis*
Cancer productus

The appearance of *Artedius lateralis* in the diet is somewhat anomalous, but the state of digestion of the fish indicates that it is not a sampling artifact.

b. Notes

No apparent mode of abundance in the kelp bed; 3 - 11% of samples. Only one individual collected outside the kelp bed. No apparent habitat restrictions with regard to exposure; more common in areas of broken substrate where it is abundant under rocks. While the ventral sucking disc indicates the possibility of tolerance to exposed conditions, the highest numbers of this species were collected at the most sheltered location within the bed. Distribution may be centred at shallower depths.

Limited observations indicate it is most active nocturnally. Sexual differentiation of the gonads possible at sizes > 30 mm.

10. *Artedius lateralis*

Number collected: 51
Size range: 24.6 - 102.0 mm
Density: 0.34 - 0.45/m^2
Estimated annual growth: 50 mm
Mean sizes: 38.8 ± 3.8 - 67.2 ± 12.7 mm
Sex ratio (/): 0.68:1.0

a. Diet

Benthic predator showing 48% dominance of gammarids followed by 24% fish, 12% shrimp and 12% crab. 10.7% empty. Species identified in the diet:

Gobiesox maendricus	*Pachycheles* sp.
Jordania zonope	*Podocerus* sp.
Betaeus setosus	*Lebbeus lagunae*
Caprella equilibra	*Photis bifurcata*
C. incisa	*P. californica*

b. Notes

The only one of the smaller resident cottids known to be piscivorous. Noted commonly in the field, much more easily identified than *Artedius harringtoni* due to the distinction regarding the scale bands above the lateral line and the profile of the head. Slightly more common in the middle regions of the kelp bed (6 - 8% of samples), although found outside the bed as well. Active fish exhibiting no timidity with regard to divers. Piscivory in this species is evidenced both by gut contents

and by observations. Smallest fish with differentiable gonads was 32.4 mm. Sexual maturity may thus be achieved in the first year.

11. *Aulorhynchus flavidus*

Number collected: 46
Density: 0.42 - 0.54/m^2

Size range: 53.0 - 119.0 mm
Mean size: 103.2 ± 2.4 mm

a. Diet

Diet consists almost entirely of nauplii (barnacle and shrimp) although shrimp, copepods and cladocerans had high occurrences. 33% empty. No specific identification of stomach contents could be made.

b. Notes

A neritic rather than a benthic form. Only the smallest juveniles were obtained in the chemical collection. This was due to the size-associated partitioning of the water column by this species, such that the smallest fish were closest to the substrate. In addition, fish were distributed horizontally by size within the kelp bed, the smallest fish being farthest away from the seaward edge of the bed. A common schooling form in the kelp bed, schools composed of 40 - 100 individuals; larger schools found near the seaward edge suggesting some facultative aspects of schooling behaviour, perhaps in response to predation pressure. Adults were directly related to the kelp plants in that the female deposited her eggs on the pneumatocysts, at the bases of the laminae. Both spawning and hatching are protracted in this species. Egg masses at different developmental stages often found on

the same plant. Egg masses were not noted on *Macrocystis integrifolia* plants, nor were nests constructed as have been described by Limbaugh (1962) for this form in California. Egg masses generally guarded by the male, although unguarded eggs were occasionally noted.

12. *Synchirus gilli*

Number collected: 43 Size range: 39.5 - 57.1 mm

Density: 0.32 - 0.42/m^2 Sex ratio (/): 3.4:1.0

Mean sizes: 43.8 ± 3.9 - 52.1 ± 3.9 mm

a. Diet

Isopods (44.4% com.) and gammarids (44.4% dom.) were the two most common diet items. 35.3% of the stomachs were empty. Species identified in the diet:

Parapleustes pugettensis *Caprella incisa*

Asellotid isopods *C. equilibra*

Amphitoe simulans

b. Notes

This species was distributed more or less uniformly throughout the kelp bed. In addition, it comprised 14% of the samples outside the bed. Although 43 specimens of this fish were obtained, little information about its ecology is available. When observed in the field, it was generally within or on bundles of *Nereocystis* stipes, often 2 - 3 mm above the substrate. Also present among *Desmarestia* spp. and *Laminaria* spp. plants. Sexual distinction of the gonads possible at sizes > 36 mm. Sex ratio is extreme among the cottids collected (*Artedius harringtoni* excepted).

13. *Xiphister atropurpureus*

Number collected: 39
Size range: 46.0 - 169.2 mm
Density: 0.31 - 0.41/m^2
Mean sizes: 74.6 ± 2.5 - 125.5 ± 26.9 mm
Sex ratio (/): 0.7:1.0

a. Diet

Stomach contents primarily gammarids (75.0% dom.) with polychaetes contributing to a lesser degree (25% dom.) in 101 - 200 mm fish. 30% of stomachs empty. Species identified in the diet:

Nereis sp. *Amphitoe* sp.
Asellotid isopods Sabellid polychaetes
Photis sp.

b. Notes

The mode of abundance of this species appears to be centred at the low intertidal, high subtidal region where it is the most common blennioid. Most common in the inner and middle regions of the bed, in areas of either high relief, broken substrate or considerable plant cover. Not taken in samples outside the bed. Secretive form, not commonly observed in the field. Large size range may indicate several year-classes present in the kelp bed; however, the sample size is too small to determine this from size frequency alone. Fish over 46.0 mm had sexually distinguishable gonads.

14. *Pholis schultzi*

Number collected: 20
Size range: 60.9 - 128.1 mm
Density: 0.13 - 0.18/m^2
Mean sizes: 76.9 ± 11.1 - 95.4 ± 6.4 mm
Sex ratio (/): 1.0:1.0

a. Diet

Smaller (0 - 100 mm) fish had only two items in their stomachs, isopods (66.7% dom.) and gammarids (33.3% dom.), while 101 - 200 mm fish had equal dominance of isopods, gammarids and caprellids. Species identified in the diet:

Parapleustes pugettensis
Asellotid isopods
Metacaprella kennerlyi
Erichtonius brasiliensis
Caprella laeviscula

b. Notes

This species is not as secretive as the majority of the blennioids, being more allied to the habits of *Phytichthys chirus*. Noted concealed in bundles of *Nereocystis* stipes and with its head projecting from rock burrows. Most abundant in the outer segments of the kelp bed. Its distribution at the Diana Island kelp bed and its absence from collections made by the author in *Macrocystis* beds supports the inference in Hart (1973) that its distribution is related to exposure. With *Chirolophis nugator* and *Anoplarchus purpurescens*, it was one of the few blennioids, and the only pholid, collected outside the bed. The largest specimen obtained in this study (128.1 mm) was a considerable increase of the maximum size reported for this species (79.0 mm, Hart, 1973). The mean sizes

of all collections but one also exceed this previous maximum. Gonads sexually differentiable at size > 60 mm.

15. *Ascelichthys rhodorus*

Number collected: 20
Density: 0.13 - 0.17/m^2
Mean sizes: 39.5 ± 2.0 - 51.0 ± 16.0 mm
Sex ratio (/): 0.83:1.0
Size range: 32.0 - 113.0 mm
Estimated annual growth: 20 mm

a. Diet

Gammarids (42.0% dom.) made up the majority of the recognizable stomach contents with caprellids contributing to a lesser degree (14.7% dom.). There were, however, large amounts of unrecognizable crustacean remains (42.9% dom.). 12.5% of the stomachs were empty. Species identified in the diet were:

Caprella incisa
C. equilibra
Parapleustes pugettensis
Acroides sp.

b. Notes

Ascelichthys was not an abundant form at the kelp bed; most common in the most exposed segments of the bed. Also collected outside the kelp bed. Not an obvious form, it was seldom observed in the field. Although most abundant in exposed environments it is secretive, found in holes and under rocks. The absence of pelvic fins in this species and the associated lack of stability may be, in part, responsible for its habits in such environments. While uncommon at this site, this species was the most common species collected in *Nereocystis* beds at Port Hardy,

B.C. Sexual differentiation of the gonads possible at sizes > 32.0 mm.

16. *Liparis mucosus*

Number collected: 15 Size range: 21.0 - 42.0 mm
Density: 0.16 - 0.21/m^2

a. Diet

Limited number examined. 66.7% isopod dominance and the remainder was crustacean remains. No empty stomachs. As with *L. florae*, the method of feeding in this species hampers identification of stomach contents. No species identified in the diet.

b. Notes

While this species was not abundant, it was common to the outer regions of the bed exposed to wave stress. Habits similar to *L. florae*. Common to *Nereocystis* holdfasts, I have also noted it in *Macrocystis integrifolia* holdfasts. Sexual distinction of the gonads possible at sizes > 28 mm.

17. *Oligocottus rimensis*

Number collected: 7 Size range: 37.8 - 45.0 mm
Density: 0.13 - 0.17/m^2 Sex ratio (/): 5:1.0

a. Diet

Stomach contents were primarily caprellids (66.7% dom.) and polychaetes (33.3% dom.). 25% empty. With regard to diet analysis, the small number of specimens examined should be noted. Species identified in the diet:

Caprella incisa *C. equilibra*

b. Notes

Uncommon form. Found in middle and sheltered regions of the bed. Behaviour unknown; this species was never observed in the field. All sizes obtained had sexually distinguishable gonads.

18. *Bothragonus swani*

Number collected: 8
Density: 0.25 - 0.33/m^2
Sex ratio (/): 1.0:1.0

Size range: 25.9 - 37.3 mm
Mean sizes: 31.1 ± 33.3 mm

a. Diet

Method of feeding in this species hampers identification of gut contents. 100% of the volume of contents was crustacean remains, but no lower taxonomic distinction could be made.

b. Notes

Uncommon, distribution may be centred at shallower depths as it is taken in tide pools. Found most abundantly in the inner segments of the kelp bed. Gonads sexually distinguishable at sizes > 26.5 mm.

19. *Coryphopterus nicholsi*

Number collected: 7
Density: 0.25 - 0.33/m^2
Sex ratio (/): 0.5:1.0

Size range: 50.7 - 79.0 mm
Mean sizes: 64.0 ± 6.5 mm

a. Diet

All specimens examined had gammarids in the gut and this group was the only dominant one. Mysids and isopods were also present. No specific identification of gut contents could be made.

b. Notes

An associated species only found outside the kelp bed. The distribution of this species at the site may represent submergence in response to wave stress, as it is found more abundantly at shallower depths in beds of *Macrocystis integrifolia*. Highly territorial species, living in and defending burrows which it excavates under large rocks. Territorial defenses were generally directed against conspecifics and against *Jordania zonope*.

20. *Nautichthys oculofasciatus*

While only two specimens were obtained in the benthic samples, 12 were captured in gillnets. Tagging studies indicate relatively localized populations, with three of the 12 tagged fish being recovered and one of those being recovered twice. Nocturnal observations show this species to be the most active of the smaller cottids; it was commonly observed during night dives. Size range of the net-caught specimens: 137 - 180 mm. Mean: 153 ± 11.6 mm.

21. *Oligocottus snyderi*

Number collected: 3 Size range: 33.1 - 54.7 mm

a. Diet

Diet diversified, though dominated equally by polychaetes and gammarids. Species identified in the diet:

Parapleustes pugettensis *Loxorhynchus crispatus*
Metacaprella anomala *Ampharete labrops*

b. Notes

Uncommon; distribution probably centred in shallower water.

22. *Blepsias cirrhosus*

Number collected: 6 Size range: 52 - 202 mm
Mean size: 138.0 ± 47.8 mm

a. Diet

Only one speciment examined for diet: contained the cottid *Clinocottus embryum*.

b. Notes

Probably nocturnal species, not observed during the day. Slight increase in maximum recorded size.

APPENDIX III

Additional Studies Conducted at Port Hardy, British Columbia

In addition to the studies conducted in Barkley Sound during 1975, the ichthyofauna of several large kelp beds in Beaver Harbour (50° 43.6' N, 127° 23' W), near Port Hardy, B.C., was briefly investigated on August 22-23, 1975. Collections were made at this location to compare the qualitative and quantitative nature of the fish community with that of smaller Barkley Sound kelp beds.

A large kelp bed of mixed *Macrocystis* and *Nereocystis* and one small *Nereocystis* bed near Deer Island (Figure 1) were examined. Overnight net samples were taken at the mixed bed as well as benthic chemical samples in both segments (i.e. *Nereocystis* and *Macrocystis*) of this bed and in the smaller bed.

1. Site Description

The mixed bed was of large size in relation to Barkley Sound beds, being approximately 15 ha. While the bed was large, it was not as dense as Barkley Sound kelp beds; the maximum density of plants in the *Nereocystis* segment of the bed sampled was 7 plants/m^2, compared with a maximum density of 35 plants/m^2 in Barkely Sound. The density of plants at Deer Island appeared to be a result of substrate limitations. There were no areas of continuous rock bottom, rather the substrate was primarily coarse gravel and large (0.5 - 1.0 m diameter) rocks. The plant distribution was contagious with regard to these rocks. A dense understory *Cymathere triplicata* (Postels and Ruprecht) J. Agardh obscured the bottom at the *Nereocystis* sampling location. The majority of these understory plants were in varying stages of decomposition, although approximately 10% were young plants. Lesser numbers of *Desmarestia viridis* (O.F. Muell) Lamaroux were interspersed with the other understory species. A relatively high degree of sedimentation and/or slight water movement in the lower water column was indicated by the covering of sediment on these understory plants.

The distribution of *Macrocystis* and *Nereocystis* plants within the kelp bed was in sharp contrast to their distribution in Barkley Sound. In Barkley Sound kelp beds were these two species were coincident, the *Nereocystis* plants were normally found in the outer, more exposed segments of the bed, gradually intergrading with the *Macrocystis* at the inner segments. The Deer Island bed showed the opposite distribution of these two species. While an overall pattern of *Macrocystis* plants at the exterior of the bed and *Nereocystis* at the interior existed, there were numerous anomalous segments of the bed where the two species intermixed. A strong tidal current might perhaps be responsible for the distribution of the plants; however, the sediment on the understory plants and observations during an extreme tidal cycle (3.5 m) indicated that tidal flow rates through the area were not excessively large.

The *Macrocystis* segment of the bed sampled was at the outer edge. The holdfasts of these plants were 8.7 m below mean sea level. The distribution of these plants was also contagious and thought to be substrate limited. The *Macrocystis* plants were large and the laminae healthy down to the bases of the fronds. Lower laminae were of the large, prostrate variety noted in sheltered locations in Barkley Sound. Understory plants were primarily *Agarum fimbriatum* Harvey, with lesser amounts of *Cymathere triplicata* and *Desmarestia viridis*.

Conspicuous benthic invertebrates were not common at this kelp bed and restricted to the two urchin species, *Strongylocentrotus franciscanus* and *S. droebachiensis* O.F. Muller. Individuals of the former were unusual for their large size (17 - 19 cm test diameter) and short spines in relation to Barkley Sound forms.

With regard to fish, this kelp bed was very unusual in comparison with Barkley Sound kelp beds in that there was a total absence of neritic fish observations during the sampling dives. A kelp bed of this size in Barkley Sound would normally support a large popu-

lation of resident and associated neritic forms.

The *Nereocystis* bed on the northeast side of Deer Island was much more similar in appearance to Barkley Sound kelp beds than the mixed bed. Plant density was approximately the same as that in Barkley Sound. The benthic flora and fauna was somewhat different with regard to both species composition and structure. Understory plants were primarily *Costaria costata* (Turner) Saunders, *Agarum fimbriatum* and *Cymathere triplicata*. Areas of substrate with low microtopographic relief, i.e. relatively smooth rock, were covered with an almost continuous aggregation of the sea cucumber, *Cucumaria curata* Cowles, all of which were extended approximately four cm above the substrate, with tentacles spread.

In common with the large, mixed bed sampled on the previous day, no neritic fish species were observed at this site during the sampling period.

2. Results of Sampling

Table 1 presents results of both net and chemical samples taken at both sites in Beaver Harbour. Diversity indices, information content and evenness values of the collections are also included. Chemical collections were all of nine-m^2 application area. Net collections were made with three nets of 2.54, 3.81 and 6.35 cm mesh size. Extensive diet analysis was not performed on specimens from these collections; however, subsamples of the collections indicated no qualitative differences between the diets of these benthic fishes and those of Barkley Sound forms. All the *Sebastes melanops* collected had empty stomachs. The stomach contents of *Gadus macrocephalus* specimens examined were composed solely of the shrimp, *Heptacarpus tenuissimus* Holmes. One of the specimens, *Myoxocephalus polyacanthocephalus* was examined and found to contain a stichaeid and a juvenile rockfish.

3. Discussion

The parallels between the kelp beds at Port Hardy and those of Barkley Sound are few. The values of the diversity indices for the benthic samples are approximately equal to those of the outer/middle kelp bed samples at Diana Island. Both the *Nereocystis* bed sample and the *Macrocystis* segment sample show highly skewed species distributions, the samples being dominated by one species which is also similar to the Barkley Sound collections. The *Nereocystis* segment collection is notable in that its diversity is much closer to the maximum diversity for such a species assemblage.

The dominance of the blennioid form, *Anoplarchus purpurescens*, in the sample from the large mixed bed infers that this bed is a relatively sheltered habitat, supporting observations made while sampling. The abundance of *Aseclichthys rhodorus* in the *Nereocystis* bed sample infers that this location was relatively more exposed, as does the presence of large numbers of *Cucumaria curata*. While the benthic fish species reflect some similarities with the Barkely Sound study site, the lack of diurnal observations of neritic fishes is unique to the Deer Island site.

In summary, the kelp beds at Port Hardy, while physically different from the Barkley Sound beds, were similar with regard to benthic species but showed no parallels with neritic forms. The availability of the neritic kelp bed habitat to colonization by fish species may be less, in terms of distance from spawning areas, than similar beds in Barkley Sound. The low density of plants at the Deer Island beds may have contributed in part to the lack of water column forms observed. This area may have great potential as a plant mariculture site since the lack of substrate appears to be the limiting factor in the determination of the size and density of kelp beds. The provision of large rocks as substrate for kelp sporophyte attachment might increase kelp density and the associated numbers of fishes.

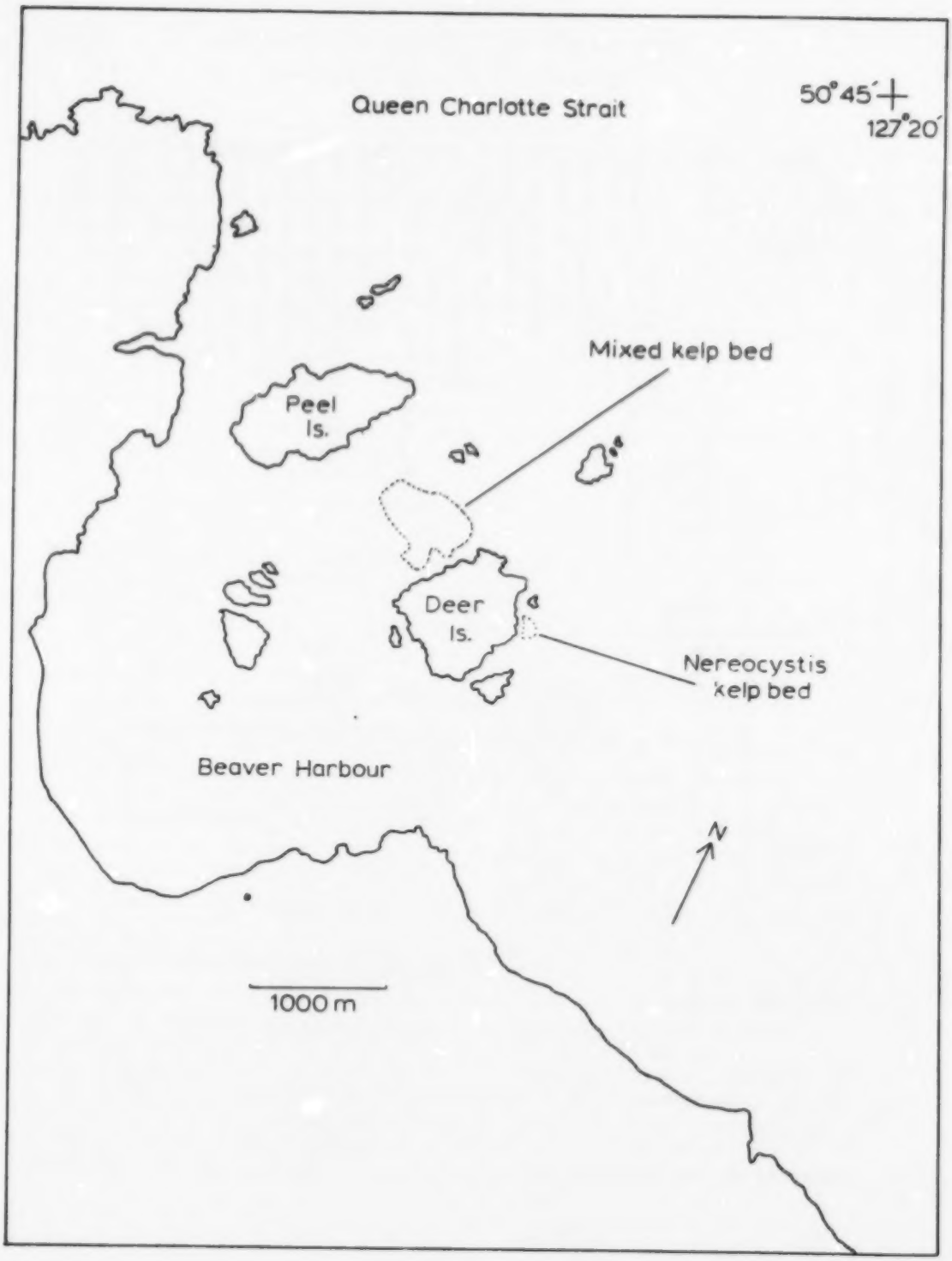


Figure 1. Location of the kelp beds sampled near Deer Island.

Table 1. Species assemblage, evenness values, information functions and diversity indices for the benthic and net samples from the Deer Island sites.

Species	22/VIII - M	22/VIII - N	23/VIII	Net
Anoplarchus purpurescens	14	13	8	
Ascelichthys rhodorus	3	3	50	
Xiphister atropurpureus	3	3	3	
Gobiesox maendricus	2	5	2	
Phytichthys chirus	2		4	
Artedius harringtoni	2	3	3	
Nautichthys oculofasciatus	1	1	3	
Jordania zonope		3	3	
Pholis laeta		2		
Hemilepidotus hemilepidotus		1	2	
Artedius lateralis		1		
Oligocottus rimensis			2	
Synchirus gilli			2	
Bothragonus swani			1	
Liparis cyclopus			1	
Enophrys bison			1	3
Sebastes melanops				15
Gadus macrocephalus				9
Myoxocephalus polyacanthocephalus				3
Brachyistius frenatus				1

Collection Date	Species Number	Individuals (N)	Diversity (H)	Information (HN)	Evenness (J)
22/VIII-M	7	17	0.07	1.19	1.006
22/VIII-N	11	35	0.70	24.50	0.023
23/VIII	14	84	0.62	52.08	0.007

M - *Macrocystis* segment of mixed kelp bed

N - *Nereocystis* segment of mixed kelp bed

GLOSSARY OF SCIENTIFIC AND COMMON NAMES OF FISHES USED IN THIS REPORT

SCIENTIFIC NAME	COMMON NAME
Agonomalus mozinoi (Wilimovsky and Wilson)	Kelp poacher
Ammodytes hexapterus Pallas	Pacific sand lance
Anoplarchus purpurescens Gill	High cockscomb
Apodichthys flavidus Girard	Penpoint gunnel
Artedius fenestralis Jordan and Gilbert	Padded sculpin
Artedius harringtoni (Starks)	Scalyhead sculpin
Artedius lateralis (Girard)	Smooth-head sculpin
Ascelichthys rhodorus Jordan and Gilbert	Rosylip sculpin
Aulorhynchus flavidus Gill	Tube-snout
Blepsias cirrhosus (Pallas)	Silverspotted sculpin
Bothragonus swani (Steindachner)	Rockhead
Brachyistius frenatus Gill	Kelp perch
Chirolophis nugator (Jordan and Williams)	Mosshead warbonnet
Coryphopterus nicholsi (Bean)	Blackeye goby
Cymatogaster aggregata Gibbons	Shiner perch
Embiotoca lateralis (Agassiz)	Striped seaperch
Engraulis mordax Girard	Northern anchovy
Enophrys bison (Girard)	Buffalo sculpin
Gadus macrocephalus Tilesius	Pacific cod
Gobiesox maendricus (Girard)	Northern clingfish
Hemilepidotus hemilepidotus (Tilesius)	Red Irish lord
Hemilepidotus spinosus (Ayres)	Brown Irish lord
Hexagrammos decagrammus (Pallas)	Kelp greenling
Hexagrammos lagocephalus (Pallas)	Rock greenling
Hydrolagus colliei (Day and Bennett)	Ratfish
Jordania zonope Starks	Longfin sculpin
Liparis cyclopus Gunther	Ribbon snailfish
Liparis florae (Jordan and Starks)	Tidepool snailfish
Liparis mucosus Ayres	Slimy snailfish
Merluccius productus (Ayres)	Pacific hake
Myoxocephalus polyacanthocephalus (Pallas)	Great sculpin
Nautichthys oculofasciatus (Girard)	Sailfin sculpin
Oligocottus rimensis (Greeley)	Saddleback sculpin
Oligocottus snyderi Greeley	Fluffy sculpin
Ophiodon elongatus Girard	Lingcod
Pholis laeta (Cope)	Crescent gunnel
Pholis schultzi Hubbs	Red gunnel
Phytichthys chirus (Jordan and Gilbert)	Ribbon prickleback
Pleuronichthys coenosus Girard	C-O sole
Porichthys notatus Girard	Plainfin midshipman

SCIENTIFIC NAME	COMMON NAME
Rhacochilus vacca (Girard)	Pile perch
Scorpaenichthys marmoratus (Ayres)	Cabezon
Sebastes caurinus Richardson	Copper rockfish
Sebastes melanops Girard	Black rockfish
Sebastes miniatus (Jordan and Gilbert)	Vermillion rockfish
Sebastes nebulosus Ayres	China rockfish
Squalus acanthias Linneaus	Spiny dogfish
Synchirus gilli Bean	Manacled sculpin
Xiphister atropurpureus (Kittlitz)	Black prickleback